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NANOSTAR PROJECT: STUDENT CHALLENGES & TOOLS - DEVELOPING A COLLABORATIVE OPEN-SOURCE PLATFORM FOR NANOSATELLITE EDUCATION AND CAPACITY BUILDING

Jorge B. Monteiro[a]*, A. Guerman[a], T. Gateau[b]*, M. Perier-Camby[c], F. Cichocki[d], M. Merino[d], J. Posada[e], Jose A. Garcia-Souto[e], A. Ghiotto[f], P. Oliveira[g], J. Cubas[h], E. Roibás[h], O. Marty[i], , M. Bernard[j], M. Romero[k]

[a] *Department of Aerospace Sciences, University of Beira Interior (UBI), Centre for Mechanical and Aerospace Science and Technologies (C-MAST), Portugal, jorge.emanuel.monteiro@ubi.pt*
[b] *ISAE-SUPAERO, Université de Toulouse, member of University Space Centre of Toulouse (CSUT), France, thibault.gateau@isae-supaero.fr*
[c] *Aerospace Valley, France*
[d] *Department of Bio-Engineering and Aerospace Engineering, University of Madrid "Carlos III" (UC3M), Spain*
[e] *Department of Electronic Technology, University of Madrid "Carlos III" (UC3M), Spain*
[f] *IMS Research Centre, University of Bordeaux, France*
[g] *LAETA, IDMEC, Instituto Superior Técnico (IST), University of Lisbon, Portugal*
[h] *Universidad Politécnica de Madrid, Spain*
[i] *Bordeaux INP, URISA / IESF Nouvelle Aquitaine, France*
[j] *University Space Centre of Montpellier (CSUM), University of Montpellier, France,*
[k] *Angolan Office for Space Affairs, Space Generation Advisory Council, Angola*

* Corresponding Author

Abstract

Nanostar emerges as a project funded by INTERREG-SUDOE through the European Regional Development Fund (ERDF) aiming to develop a collaborative platform in Europe for nanosatellite hands-on education and training in space engineering. One of the major project goals was to develop a set of open-source tools for nanosatellite subsystems design, which are interconnected through a centralized database. Although the Nanostar project provides a first version of such a default tools set, the open-source community can still adapt it to its own needs in the future. This first set of collaborative tools and modules is called "Nanostar Software Suite" (NSS), and a preliminary version has already been tested in both international and interinstitutional preliminary mission design competitions and detailed design challenges. The received student feedback has allowed to refine the NSS and to adapt it to its main target user: the students. The NSS implements a Concurrent Design Engineering methodology thanks to a set of integrated tools. These tools rely on both a strong modularity and the use of standards, which should ease incorporation of external materials. The NSS is composed of a set of modules that can easily communicate through Nanospace. Modules have been provided, developed, and supported by the different institutes of the Nanostar Consortium. The Nanospace is the NSS backbone, allowing a smooth interaction between each subsystem tool. Contrary to existing solutions, the NSS is open-source, meaning that the architecture allows the integration of 3rd party tools and applications. The NSS aims at getting a strong data consistency between expert software during a mission preliminary design. This paper focuses on summarizing the Nanostar project, as well as proposing future applications. Thus, it describes the work performed, detailing specific aspects of the NSS, as well as the outputs of the student challenges. Also, an ecosystem analysis is performed to understand the state-of-the-art solutions and services in the context of hands-on undergraduate education on small satellite preliminary design in Europe. This allows to define the value proposition of Nanostar and the NSS competitive advantage compared with existing tools for concurrent engineering in preliminary mission design. Finally, it draws conclusions about the potential of NSS for space education and proposes concrete strategies and applications for the future.

Keywords: #opensource #nanosatellite #CubeSat #education #concurrentdesign #concurrentengineering #nanostar

Acronyms/Abbreviations
API: Application Programming Interface
CDF: Concurrent Design Facility
CE: Concurrent Engineering
DDSE: Data Driven Systems Engineering
COTS: commercial off- the shelf components
IDM: Integrated Design Model
MBSE: Model Based Systems Engineering
NSS: Nanostar Software Suite

1. Introduction

Nanostar is a project funded by the Interreg Sudoe program through the European Regional Development Fund (ERDF) to support the development of a network in Southwest Europe capable of training students in space engineering and project engineering, so that they become the future main players in the field of nanosatellites. The goal was to demonstrate a novel collaborative approach to provide the high-level skills and experience around a real space engineering process that includes all stages, from conception and specifications, to design, assembly, integration, testing, and documentation [1,2]. The consortium, from France, Spain, and Portugal, was composed of 7 universities and 2 aerospace clusters plus 3 ESA-BIC (Business Incubation Centres of the European Space Agency) as associates.

This paper focuses on summarizing the Nanostar project outputs, as well as proposing future applications and improvements. It is divided in 8 sections. Firstly, it starts with a brief description of the project. Secondly a literature review and ecosystem analysis are performed about the current solutions and services for small satellite undergraduate education and capacity building, focusing on Europe. Secondly the methodology used is described and explained. Thirdly, the methodology and requirements are explained Fourthly, the work performed is detailed, which includes specific aspects of the tools developed and lessons learned. Fifthly, the student challenges are presented, and the feedback assessed. Sixthly, the results are discussed and suggestions for improvements are proposed. Finally, an assessment to the value proposition of Nanostar and a potential roadmap for the future is presented, with final conclusions.

2. Background and ecosystem analysis

This section reviews existing solutions and services on small satellite education and concurrent engineering tools used for the design of space missions in education and research context.

2.1 State-of-the-art on small satellite education

Nanosatellites are nowadays adopted by education and research organizations as a training and innovation tool in the field of space systems engineering and management, which allows more risk at reduced costs and timeframes. Interest in this technology started with the rise of CubeSats, a standardized subclass of small satellites, that decreases the complexity of space projects. The standard was created by Stanford and California Polytechnic State Universities in 1999, and it specifies that form factor of one unit (1U) represents a 10-centimeters cube with a maximum mass of 1.33 kg. The standardization promotes a highly modular, highly integrated system where satellite components are available as commercial off the shelf (COTS). Moreover, it allows them to be launched as secondary payloads within a standardized deployment system. This simplifies the accommodation on the launcher and minimizes flight safety issues. Due to these features, CubeSats can also be readied for flight on a much more rapid basis compared to a traditional spacecraft. This accelerated schedule allows students from universities with a CubeSat program to be involved in the complete life cycle of a mission, but also research organizations to test in-orbit technology faster [3,4]. Several educational and research approaches that use this class of satellites have been growing since then and there is now a variety of services that are being provided in the field of education and capacity building about small satellites, as well as in the development of concurrent engineering tools for preliminary design of space missions. Some organizations do it for commercial purposes whereas others are non-profit. The following solutions stand-out in Europe:

2.1.1. Libre Space Foundation (Greece)

A non-profit foundation composed by an international community of researchers, industry and individuals that share the vision for open-source technologies in space. They share methodologies, ideas, best practices, code, and designs of open-source space technologies, on-line and in-person. They also develop research open-source projects, and they offer the following services: mission design, satellite design and development, testing, ground station services, rocketry operations and training [5].

2.1.2. Space Challenges - Spaceport (Bulgaria)

Space Challenges, part of Tsiolkovsky Association, is the biggest free educational program for space science, technology, and exploration in Central and Eastern Europe. By leading expertise in the field of technology and science, they have created an advanced outreach program for exponential technologies and space science for young people (age 16-28). The online Spaceport program involves a range of leading experts providing lectures online with a short test at the end of each topic. It is designed with a gaming approach, meaning that students need to complete specific achievements to earn points and medals. This approach motivates students to complete tasks and certifies them in specific topics, which can help with future recruitment. The program is complemented with an optional intensive hands-on physical academy of 4 weeks in Bulgaria with workshops, team challenges and core lectures [6].

2.1.3. Sputnix - Orbicraft (Russia)

A private company based in Russia. It offers a range of educational equipment and resources for individuals, companies and teams looking to expand their knowledge and capabilities of space engineering and related concepts. The portfolio includes the Orbicraft satellite kit, which is a set of electronic and mechanical parts for the manual assembly of CubeSat-compliant spacecraft. The starting price is 3200€ for the basic kit, and 6335€ for the payload development kit [7].

2.1.4. Theia Space - ESAT (Spain)

A private start-up company from Universidad Politécnica de Madrid, Spain. They have developed ESAT, which is an educational satellite designed for hands-on training in space engineering. ESAT users can integrate and test their own developments, both software and hardware, making it possible to share and exchange new ideas, and to collaborate in new developments. The starting price is 6976€ for the ESAT nanosatellite and 987€ for the Ground Support Equipment [8].

2.1.5. Arctic Astronautics - KitSat (Finland)

The company operates in the field of space education. KitSat offers a fully functional satellite to schools, science centres and anyone who wants to learn how to build a CubeSat from scratch. The company span out from Aalto University Student Satellite Team. Kitsat is based on the CubeSat format and is delivered with a ground segment unit for realistic satellite operations simulation. The starting price for the kit is 1895€, and, in addition, the company offers classroom training sessions and online access to support and learning [9].

2.1.6. OrbAstro – Flatsat (UK)

A private entity with expertise in small satellites, which is organizing a student competition to allow universities to use their Flatsat. Teams mature the design of their novel spacecraft payload and program it up for satellite integration using hardware and software modules on the Flatsat. The competition entry fee is £500. Universities can either hire a flat-sat and associated software modules at £300 per month, for the full duration of competition participation, or they can purchase a flat-sat outright for £2,500 upfront with associated software/technical support for one competition [10].

2.1.7. HEPTA-Sat (UNISEC)

Hands-on Education Program for Technical Advancement (HEPTA-Sat), used as a training kit for the public who wants to know more about satellites or who aims to develop a full satellite. It consists in a study of small satellite design and engineering over several days of intensive practical lessons performed at the educational centres of the University Space Engineering Consortium (UNISEC). The training consists of a hands-on learning step with CubeSat type classroom satellite kit. The course is designed to teach students about different sub-systems, how to integrate and test/debug them [11].

2.1.8. Fly Your Satellite (ESA)

It is an educational program whose focus is the verification campaign of CubeSats built by university students. The program offers students the opportunity to benefit from the transfer of technical competence and experience from ESA specialists. In addition, the program aims at increasing CubeSats missions' chances of success. The program is structured in four phases, from the integration of the CubeSat Flight Model up to the operation of the satellite in space. During each phase, CubeSats must undergo expert reviews which need to be passed to access the following phase [12].

2.1.9. AMSAT - Cubesat Simulator (USA)

The CubeSat Simulator is a low-cost satellite emulator that runs on solar panels and batteries and transmits UHF radio telemetry. It has a 3D-printed frame and can be extended through the addition of other sensors and modules. This project is sponsored by the not-for-profit Radio Amateur Satellite Corporation (AMSAT). It is an excellent tool for education and demonstrations. It can be used in a classroom or training setting to introduce the basics of satellites, it can be used to teach fundamental concepts, or as a steppingstone in a project to build and launch an actual flight model CubeSat [13].

2.1.10. Open Cosmos – OpenApp and OpenSat (UK)

A private company based in the UK focused on satellite solutions. It also offers education resources that include the OpenApp and OpenKit which allow students to simulate entire missions and develop flight-ready payloads. The starting price is 2000£ for education institutions. OpenApp is an online software-as-a-service platform that supports each of the phases of a space mission. OpenKit is a satellite qualification platform which allows users to develop their technologies against real physical interfaces that are fully compatible with Open Cosmos' nanosatellite platforms (OpenSat). It can be used to functionally test and validate systems to reach flight readiness. Open Cosmos also stands out by offering a very intuitive and user-friendly application and for building a community through partnerships with universities and student organizations (such as SGAC) to promote their tool. They have a program called "ambassadors", which enables SGAC members to become ambassadors (specialists working with the tool) and then they can provide training on Open Cosmos behalf [14].

2.2 State-of-the-art on concurrent design tools

The design process of a complex engineering system, such as a satellite, is full of inter-dependencies that require the involvement of different domain experts and continuous information exchange. Model Based Systems Engineering (MBSE), Data Driven Systems Engineering (DDSE) and Concurrent Engineering (CE) have proven to reduce the time needed for feasibility studies and conceptual design of space missions [15]. Some tools have been developed and used in Concurrent Design Facilities (CDFs) to support the collaborative work. The following tools stand-out in Europe, with a non-exhaustive comparison in Fig.1.

Group	CONCURRENT CONCEPTUAL DESIGN TOOLS					
Tool	IDM	VirSat 4[1]	OCDT	CDP 4[2]	Valispace[3]	CEDESK[4]
References	Bousquet et al. [2005]	Schaus et al. [2010], DLR [2016]	ESA [2014], Braukhane [2015]	Fijneman and Matthyssen [2010], RHEA-Group [2019]	Valispace [2017]	Knoll and Golkar [2018]
Aspect						
Multi-User Support	Yes	Yes	Yes	Yes	Yes	Yes
Lifecycle Phase Focus	conceptual design	conceptual design	conceptual design	conceptual design	conceptual design	conceptual design
Parametric modeling Focus	behavior	behavior and geometry	behavior	behavior	behavior	behavior
Version Control	Limited	Yes	Yes	Yes	No	Limited
Primary User Interface	Excel™	Own client	Excel™	Own client, Excel™	Own Web	Own client
Integration With 3rd Party Tools	No	No	Yes	Yes	Yes	Limited
Availability	ESA community	Open Source	ESA community	Open Source	Commercial	Open Source

Fig. 1. Overview of concurrent design tools [15].

2.2.1. Valispace

Valispace is a concurrent engineering tool and browser-based platform for collaborative development of hardware projects. The product offers a wide variety of features to ensure teams can collaborate on all aspects of the design. The application stores engineering data and lets the users interconnect them through formulas and processes. So, when one value is modified, the system updates, simulations are re-run and documentation is rewritten automatically. The software can be used for free for educational purposes [16,17].

2.2.2. OCDT - Open Concurrent Design Tool

OCDT is a server software package developed under an ESA contract to enable efficient multi-disciplinary concurrent engineering of space systems in the early life cycle phases. It implements a standard semantic data model defined in Annex A of the ECSS-E-TM-10-25 Technical Memorandum, titled System Engineering - Engineering Design Model Data Exchange (CDF). The first implemented OCDT client is an easy-to-use add-in for Microsoft Excel to perform simple analysis and simulation. Other client tools for engineering analysis and simulation can also be integrated, using OCDT adapters. The OCDT server consists of a front-end web-services processor (using a REST API) and a back-end PostgreSQL database system for the persistent storage of OCDT shareable data. The server can support concurrent teams with synchronization of their engineering model content. The package is distributed under an ESA community open-source software license available for use and further development to users that qualify as a member of the OCDT Community [18].

2.2.3. Integrated Design Model (IDM)

The IDM was developed by the initiative of ESA's General Studies Program to support the concurrent engineering approach. It is based on Microsoft Excel. It has been in operational use for more than 10 years now and has supported designing systems in over 100 ESA studies. The IDM is both a hierarchical model for space systems and a distributed implementation of the model in Excel [19]. IDM is being explored by CNES.

2.2.4. CEDESK - Concurrent Engineering Data Exchange Skoltech

CEDESK is an open-source collaboration tool to speed up and parallelize conceptual design studies of engineering systems. The tool facilitates co-located collaborative model-based conceptual designs for complex engineering systems and is also known as data exchange for concurrent engineering studies [15,20].

3. Nanostar requirements and methodology

Nanostar aimed at developing a collaborative and open-source online platform to provide relevant training on nanosatellite concurrent engineering through hands-on student challenges (described in Section 5). On the one hand, the consortium developed the Nanostar Software Suite (NSS), an open-source suite of tools and processes for concurrent design of small satellite missions. On the other hand, a methodology document to orient students in the complex field of nanosatellite engineering was also completed and made available to them before they started the above-mentioned student challenges.

3.1. Requirements for the NSS

The goal of NSS was to allow concurrent design engineering of nanosatellite missions at undergraduate level. So, it should comply with the following requirements: (1) to be open-source (AGPL & MIT licences); (2) to be highly modular and easy to integrate with 3rd party tools in order to allow users to keep their favourite expert tools; (3) to be ergonomic, user-friendly and oriented for education; (4) to be web-based and allow remote work and multiple access from multiple sites; (5) to use database rather than spreadsheets; (6) to respect the standards CCSDS insofar as possible.

The Fig. 2 shows the expert tools that were identified as candidates to be integrated in the NSS.

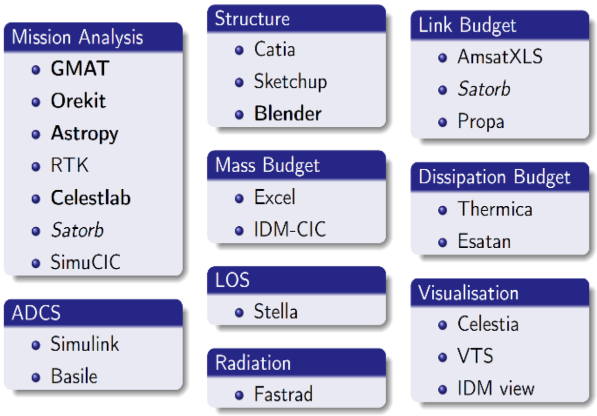

Fig. 2. Candidate software list for NSS.

3.2 Methodology for preliminary mission design

Apart from developing a new software suite for concurrent engineering, one of the goals of the NANOSTAR project was to provide the students with a set of definitions, instructions and standard procedures that must be understood and followed in the preliminary design of a nanosatellite mission, like the ones undertaken during the preliminary design competitions organized by the consortium (see Section 5). Therefore, a methodology document was developed and uploaded to the official NANOSTAR website (https://nanostar-project.gitlab.io/main/) in order to guide the students in their work.

4. The Nanostar Software Suite (NSS)

This section focuses on providing the technical specifications for the NSS and pointing out the advantages of these tools in comparison to current ones.

4.1. Technical Specifications

The backbone of the NSS is Nanospace software [21]. Nanospace is an open-source software developed at ISAE-SUPAERO dedicated to facilitating the preliminary design of CubeSats for remote teamwork. It includes three main components (see Fig. 3): a web-based GUI (Nanospace-UI); a database with ACID properties (Nanospace-DB); a RESTful API through Nanospace-Service. Nanospace is open-source (AGPL v3 license), and its source code is available at: https://gitlab.isae-supaero.fr/nanostar/nanospace.

New models and interfaces can be developed and added progressively complying with the needs of the users (see Fig. 4).

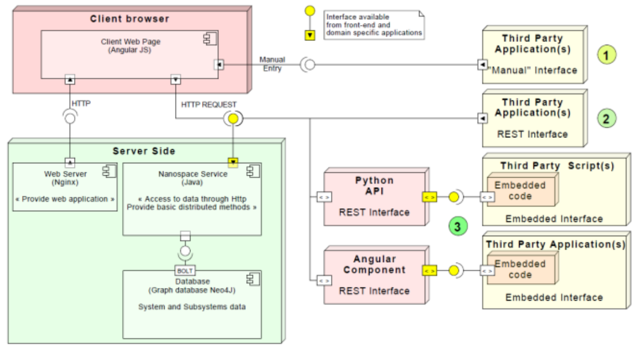

Fig. 3. Nanospace architecture [21].

As seen in Fig. 4, the NSS architecture is not static, and anyone can connect its own 3rd party application through three different alternatives: (1) manually interacting with the NSS Web User Interface ("shared spreadsheets style") if the 3rd party is a black box; (2) embedded code: an Angular component and a python API are provided to ease code integration; (3) full compliance with the Nanospace REST API: allowing to develop an independent service application directly interacting with the database.

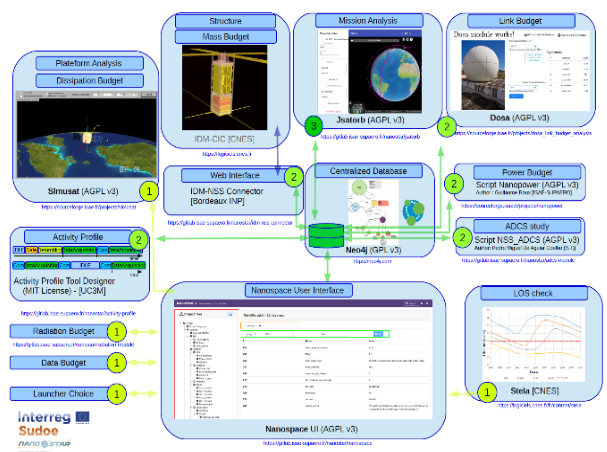

Fig. 4. NSS architecture for the first prototype.

NSS implements a Concurrent Design Engineering methodology thanks to a set of integrated tools. These tools rely on strong modularity, standard respect and should ease incorporation of external materials. Modules are provided, developed, and supported by the different institutes of the Nanostar Consortium. The Nanospace module and its associated database are the backbone of NSS, allowing a smooth interaction between each subsystem expert tools [21]. Fig.5 presents the current tools that integrate the NSS and are used within it.

Module	Base Tool	Interface	Responsible
BDD	Nanospace	REST-API	ISAE
Mission Analysis	JSatorb	REST-API	ISAE
EPS	Nanopower	Python API	ISAE
Link budget module	Dosa	Node JS	ISAE
Data budget module	Dat-mod	Python API	ISAE
Thermal architecture	-?-	-?-	UM
Radiation budget module	Rad-mod	GUI	UPM
Mechanical architecture	IDM-CIC	dedicated	-
Dedicated Interface	Idm-nss-con.	NodeJS	BINP
Preliminary ADCS sizing	NSS-ADCS	Java API	IST
Activity Profile	Act-pro	Python API	UC3M
Long term propagation	Stela	GUI	-
Visualization	VTS	JSatorb	-

Fig. 5. Current state of NSS modules development.

NSS aims to help getting a strong data consistency between expert software during a mission analysis preliminary design. The goal is to provide a set of open-source tools that can be used for designing each subsystem of a CubeSat, interconnected through a centralized database. The Nanostar project provides an instantiation of such a set of default tools, but the open-source community can still adapt it to its own tools. The whole NSS project source code is available at https://gitlab.isae-supaero.fr/nanostar/, while some tutorials on its use can be found at https://gitlab.isae-supaero.fr/nanostar/nss-tutorials.

4.2. Weaknesses and strengths

Compared to the current tools, the NSS major disadvantage is the fact that it is still in the prototype stage, and that it still lacks some documentation and tutorials, as well as a simplified installation process.

On the other hand, it has the main advantages of being highly modular and open-source, which is very useful for education and research purposes. Contrary to existing solutions, NSS focus on the integration of 3rd party tools. Thus, one should be able to replace an existing module using its own expert tools, with minimum effort. Also, NSS is built in a remote team-located work and open-source spirit. Most of the software which constitute the Suite are under AGPL v3 or MIT license. Finally, NSS is meant to be for educational purposes, therefore it is not a heavy client application, but composed of a set of modules that can easily communicate together through Nanospace and its associated database.

4.3. Take-away lessons and future steps on NSS

At the current prototype stage, NSS is a centralized collaborative web-platform capable of integrating open-source tools used in satellite mission planning and design. However, the final goal is to develop a centralized, modular, and collaborative working environment via web-platform that can integrate open-source and expert tools regarding project management and engineering of nanosatellites for all mission phases.

For future work, it is proposed to check the platform resilience by testing the tools and integrations; ease the installation and setup processes; produce tutorials and documentation with real mission examples; increase and complete the integration between modules and Nanospace UI (it should all be fully compliant REST API); develop more modules and life-cycle beyond phase 0/A; integrate more open-source tools; develop a formal pipeline management; perform a proof of concept. Finally, it would be great to validate the full NSS by developing and launching a Cubesat that was modelled entirely using it.

5. The student challenges

Several student challenges were organized during the project with the following main goals: to provide a realistic test bench for both the methodology and the NSS proposed software tools. At the time of the challenges, the NSS was not yet available to students, so that the obtained feedback was mainly on the individual design tools; to train the first cohort of students from the Nanostar network; to demonstrate a collaborative education model, with support faculty and teamwork.

Regarding this last point, Fig. 6 shows a schematic of the organization of the student challenges, which aimed to be as much collaborative as possible, taking advantage of the available expertise across institutions. Challenges were undertaken by teams of students (e.g. 5 students per team in preliminary mission design challenges), which could communicate between them but also with their institution supervisor and with experts from all the consortium that constituted the so-called support faculty. Finally, a panel coordinated by UC3M and B-INP was in charge of proposing the preliminary mission design challenges (including top-level mission requirements and competition rules), defining the detailed design challenges so that they covered as many areas as possible of a full nanosatellite engineering model, and evaluating the work done by the students.

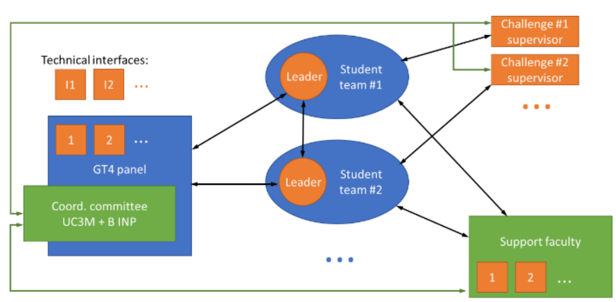

Fig. 6. Nanostar collaborative education model for student challenges.

Two types of challenges were organized: two competitive preliminary design challenges (generally taken by teams of 5 students), and detailed design, manufacturing, and test challenges, which were different in each institution (according to both the local institution needs and expertise) and also carried out by student teams (although with a variable number of students from 1 to more than 10). The timeline associated to these student challenges is shown in Fig. 7, together with the periods dedicated to the evaluation of the work by the evaluation committee.

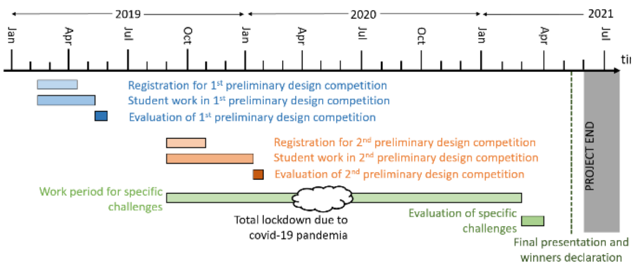

Fig. 7: Timeline of the student challenges.

Overall, nearly 300 students from the consortium institutions participated in the challenges and more than 70 student teams delivered their work in the form of a design document, technical contents and/or oral presentations. A total of 21 design tools were used throughout the student activities, with 2 seminars per university on the use of IDM-CIC, the base tool for preliminary mission design challenges. Regarding the feedback, a total of 42 students sent it to the consortium at the end of the preliminary design competitions, a very valuable inputs for further developments of both the NSS and the methodology.

5.1. Preliminary Design Challenges

The space mission preliminary design challenges were competitions in which multidisciplinary teams of students from the Nanostar universities had to present a phase 0/A preliminary design for a complete nanosatellite mission, using the NSS suggested tools, and, in particular, the IDM-CIC tool for the structural design part. Two preliminary mission design competitions were proposed and completed.

5.1.1 Moon's Fly-by with a nanosatellite

In this mission scenario, each student team had to design a nanosatellite capable of reaching the Moon to observe its surface and thin atmosphere, in search of water. A total of 15 teams participated in this competition, and the corresponding deliverables can be consulted at: https://nanostarproject.eu/student-challenges/registration-phase-i/student-deliverables-first-edition/

The Lunar fly-by trajectory computed by the winning team of this competition (named *UBI Moon Invaders*) is shown in Fig. 8, while Fig. 9 shows the manufactured non-functional engineering model of the nanosatellite designed by the 2nd classified team (*UC3M Cubesat Chefs*) and built as part of a dedicated detailed manufacturing challenge. Furthermore, *UBI Moon Invaders* presented their winning design at the 3rd Symposium on Space Educational Activities, in Leicester, in 2019 [22].

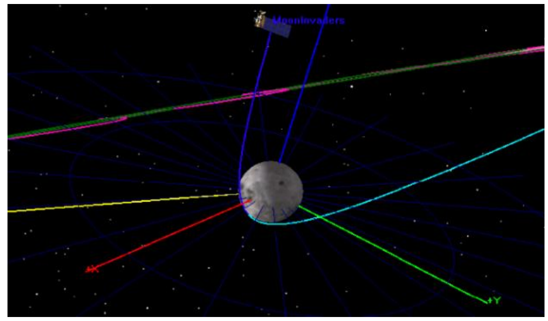

Fig. 8: Fly-by trajectory around the Moon computed by the winning team of the 1st preliminary design competition (*UBI Moon Invaders*).

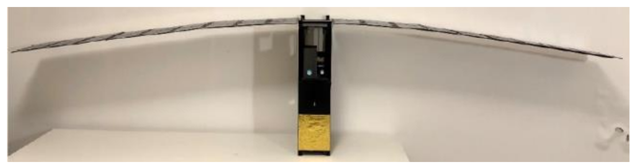

Fig. 9: Manufactured model from the design of the 2nd classified team (*UC3M Cubesat Chefs*) of the 1st preliminary design competition.

5.1.2. Biological payload demonstration

In this mission scenario, the goal was to demonstrate the successful in-orbit operations of a biological payload (carrying Roscoff's worms) aboard a nanosatellite orbiting the Earth. A total of 6 teams completed the design and the corresponding deliverables can be consulted at: https://nanostarproject.eu/student-challenges/registration-predesign-challenge-second-edition/student-deliverables-second-edition/

The winning design by *UC3M Starworms* student team is shown in Fig. 10 with an exploded view of the satellite. The L-shaped black box represents the payload.

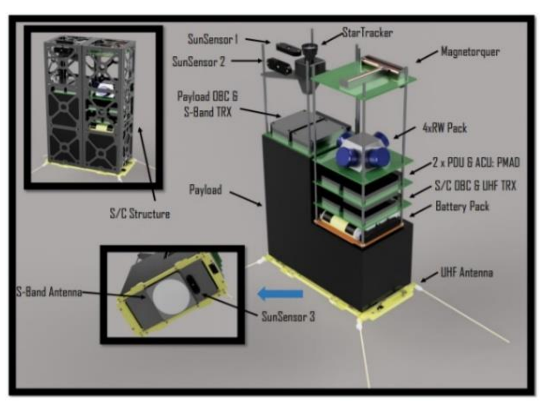

Fig. 10: Exploded view of the winning design of the 2nd preliminary design competition *(UC3M StarWorms)*.

5.2. Detailed Challenges

Detailed design, analysis, manufacturing, and test challenges were dedicated to specific research topics about small satellite subsystems or components that could lead to a final Bachelor or Master of Science thesis, to be addressed either in teams or individually. These dedicated challenges could be of four different types: (1) design, using dedicated tools, of a component or a subsystem of a nanosatellite; (2) analysis of relevant problems and/or proposal of innovative techniques related to nanosatellites; (3) manufacturing or in-scale reproduction of a relevant component/system/subsystem; (4) testing of some type of infrastructure/hardware/ algorithm of interest for nanosatellites.

Nearly all relevant areas of a complete nanosatellite system (including ground, launch and space segments) have been covered, with a total of 49 completed challenges in 6 different institutions. All information is available online at: https://nanostarproject.eu/active-challenges/. A summarizing picture of the relevant engineering areas covered by the organized detailed challenges is finally shown in Fig. 11.

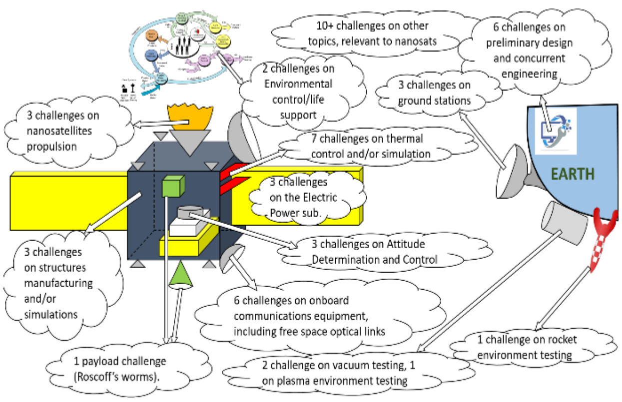

Fig. 11: Relevant Nanosatellite engineering areas covered by the detailed Nanostar challenges.

Finally, the winning team of the detailed challenges (DZH Dynamics) presented a full design of an inertia-morphing nanosatellite prototype that was recently selected by the ESA's *Fly Your Satellite* programme. More information can be found at: https://nanostarproject.eu/development-of-an-inertia-morphing-nanosatellite-prototype/.

5.3. Feedback and take-away lessons on challenges

The students provided some very valuable feedback after the student preliminary design challenges on the NSS tools, methodology and challenges organization. Find below the relevant points.

Regarding NSS, many students asked for training in mission analysis tools, and in structural design tools. Such training could be organized simultaneously at all institutions by organizing remote seminars. They also asked the functionality of connecting different structural design tools apart from IDM-CIC, such as Catia or Solidworks, and the inclusion of a thermal analysis tool.

Regarding the methodology used, the students asked for an improvement of the contents (especially telecommunications and structural design sections) by adding more explanatory videos, pictures, and technical design examples. Also, some formulae should be revised, and their explanation improved. A glossary for the considered symbols should be added for each subsystem to ease the reading and understanding. To add, it was required more information on management, and additional tutorials on this topic. Most of the time, students know little about team management at the beginning of the project and cannot put it in practice until too late in the challenge. This also includes project management guidelines.

Regarding the competition, there should be an earlier announcement of the challenges, at least 3-4 months before the registration opens, and the evaluation criteria must be ready at the very start of the challenge. Moreover, most students complained about the short available time for work (3-4 months, see Fig. 7) and about the deadlines of the challenge being close to final exam sessions. The best solution to this is to organize yearly preliminary design challenges with up to 9 months of work time and avoid crowded times. This way the workload would be more distributed across the academic year. Finally, there was required more remote and shared workshops/seminars on specific topics and a more inter-institutional approach, where students could work in international environments and select challenges from other universities (regarding the detailed challenges).

6. Results and discussion

From the challenges and feedbacks, we were able to infer several conclusions about student needs. One of the main student concerns was that the organized challenges have offered an insufficient number of formation seminars for the use of the suggested software, and from an insufficient formation of inter-institutional teams. Also, they refer that some contents could be improved (more explanatory videos and examples, more information on team management). For what concerns the concurrent engineering the use of CDF rooms at the Nanostar institutions has been limited (only about 1 student out of 10 actually used them).

However, the overall feedback and feeling was good with the majority of students evaluating positively the challenges and a number of participants higher than expected for a first trial. Based on this premise, we conclude that this type of initiative is very well accepted and may be suited to serve as a promising methodology to foster space and project engineering. It might although need some improvements. In future collaborations, cross-sectorial, industry-driven, and cross-border challenges could be reinforced. The management of a project in a multicultural context is an asset that could be provided to the students in addition to the technical skills developed.

From the student concerns, there is a need to have access to more information and training given their different backgrounds, and to get more assistance through the project. This reinforces the importance of doing complementary initiatives to the challenges, such as workshops, lectures, talks, seminars and online documentation and methodologies. A solution is to move to more open-source education and the use of e-learning tools. It would be possible to develop a Massive Open Online Course (MOOC), where different institutions participate and disseminate knowledge through several fields in the context of space and project engineering. Those lectures would be available online. Also, there could be schedule meetings in the CDF rooms between students and inter-institutional professors and researchers. Finally, courses are implemented along with the Nanostar Software Suite which is a key of success in the student training. This tool, still in development, needs to be sustainable and financially viable to be fully integrated in space curricula.

Regarding research on nanosatellites, this only can be possible through two ways: investment for resources or the participation of external actors that can facilitate it. Nanostar has allowed students to participate in several scientific research and innovation projects, but only because it included a budget that allowed the universities to conduct such research. Another way to do this, is to establish partnerships with external organizations that would benefit from having the students there, through internships or side research projects.

7. Potential value and future strategy

From the ecosystem analysis section, it is possible to conclude that there is a variety of services that are being provided in the field of education and capacity building about small satellites, as well as in the development of concurrent engineering tools for preliminary design of missions. Some organizations do it for commercial purposes whereas others are non-profit. They also use different approaches to provide their services. This section discusses the potential value of Nanostar within this ecosystem and proposes strategies for the future.

7.1. Comparison and value proposition

Most organizations that are oriented to education focus on developing end-to-end solutions, meaning that they develop both software and hardware tools that can be used together for educational purposes. To this extent, Nanostar is behind, because the consortium did not develop hardware tools yet.

Another important topic is documentation. There is a big effort from all the ecosystem to provide online tutorials, videos, helping guides and make it available online and for free. Nanostar consortium has already laid the foundation for providing online content through the website. However, there is the need to develop much more. NSS is constantly updating, so updating the documentation is required

On the other hand, most organizations do not provide a complete concurrent engineering tools neither open nor modular tools, rather they focus on specific expert tools for commercial purposes. This means that the NSS has the potential to become the number one free and open-source tool and a connector between those expert tools.

Accordingly, Nanostar has the potential to add value to the services already in the ecosystem. Firstly, the consortium is composed by high-level experts in the research and development of small satellites, but also with years of experience in education of university students. Therefore, it can provide high-level education that cannot be comparable to the one provided by the start-ups or industry. Secondly, it has developed state-of-the-art tools for the design of space missions. The tools are specially designed for students and for small satellites, and are open source, meaning that they can be improved. Thirdly, Nanostar has developed and tested a formula for hands-on education activities with a huge adherence rate from students. Challenges with prizes motivate students to work on research projects and collaborate internationally. Finally, Nanostar has already set a strong basis for small satellite training in Europe. During the project, it has built a community of researchers and students and given them the resources to collaborate in projects.

To summarize, Nanostar consortium can deliver the following value: (1) provide online education and capacity building in space engineering on small satellites; (2) organize educational hands-on challenges; (3) provide access to collaborative and open-source software tools for space mission analysis and design; (4) provide technical support and expert advice to use those tools; (5) provide access to a network of experts and resources in space engineering; (6) and develop a community for research and development in the small satellite field.

7.2 Potential value for education in Africa

Due to its political, social, and economic conjuncture, Africa has followed with relative delay the global evolution in the space sector. The main reasons are the small belief or knowledge about the benefits of space, and the reduced level of digital literacy, infrastructures, and capacity building in different areas. However, space development can help the continent to face some of the major problematics: climate and environmental changes, education, and employability of young people.

To support Africa, the European Commission has recently adopted a comprehensive strategy with Africa to answer the emerging challenges. The adoption of space-based solution, development of space agencies in the

African continent is the new Eldorado for space activities. Small satellites represent a huge opportunity for the economic development, security on land and in oceans, citizen wellbeing and education matters. If many contracts for the building of satellites are signed with non-African countries, training the new generation in space sector such as nanosatellite designers is an important success factor to enhance the youth employability which can be tackled by tools like Nanostar and allow that African countries can guarantee their medium and long-term entry into the space sector.

A successful capacity building can only happen when potentially (multiple) users are tied into the satellite. Most capacity building in developing countries is happening with the intent that the knowledge of satellite building is going to trickle down and ignores the fact that the output needs to be tailored to users who can then create more demand for such assets to be able to continue building satellites. The space community seems to work in isolation of last mile problems in such countries and needs to really make an effort of connecting with the users in different verticals for societal benefit and providing a return on investment.

Africa can confidentially boast of 3 regional satellite missions design programmes. One of which, is the HumbiSat programme, which is the first fully pan-African satellite missions design programme, with a goal oriented towards the launch of Africa's first Pan-African small satellite. HumbiSat project will incorporate space education (space systems engineering, entrepreneurship, project management and law), with community outreach through interactive workshop and satellite missions design facilitation and for that the main choice is Nanostar along with other complementary tools. The same happens with similar regional and cooperative nanosatellite programmes that already demonstrated their needs of a tool with specifications of NanoStar. There also a sign of opportunity looking into the fact that more than 50% of the Top 300 universities in Africa already had at least tried to start nanosatellite activities by themselves or through different international and government capacity building programs.

7.3 Strategy for future sustainability

Nanostar, as any government funded project, has an end. So, its continuity depends on more funding and support until it becomes self-sustainable. To arrive at that point, Nanostar shall propose a follow-up project within the new European strategy for education and research in the space field. The focus of this new project must be to continue training the next generation of aerospace professionals through nanosatellite hands-on challenges based on research aspects; continue the development of NSS up to the point where it becomes an open-source product; develop user's documentation, training tutorials and workshops around NSS and make it easy to install and use; develop a nanosatellite mission modelled through the NSS and its respective modules.

After this, Nanostar can become self-sustainable with open-source solutions. We propose two solutions for the future: Nanostar Academy and Nanostar Expert. The Nanostar Academy would be a certified program on hands-on in space project engineering to rapidly qualify professionals for the future space workforce. The Nanostar Expert would be a network of specialists to provide technical support and specialized knowledge.

Regarding the organizational structure, it is advised that Nanostar adopt an open and volunteer structure around a community of users and contributors such as students, developers, researchers, and academics. The users would use the tools to develop nanosatellite missions and systems, while contributing with requests, feedback, bugs fixing and tool development. On the other hand, the contributors would be able to be lecturers in the Academy, experts, human resources of the organization, or even partners and sponsors. In Fig. 12, the organizational structure proposed for the future sustainability of Nanostar is presented.

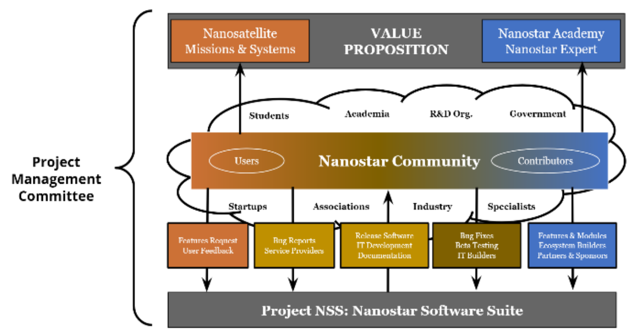

Fig. 12. Proposed organizational structure.

8. Conclusions

This paper focuses on the work developed within the Nanostar project framework, a collaborative platform for providing relevant training in nanosatellite missions, from engineering to project management. Findings and results were presented and discussed.

Two preliminary design challenges and around 50 detailed design, analysis, manufacturing and testing challenges were organized and a suite of open-source tools for concurrent design were developed that can be improved continuously. More than 300 students participated in the student challenges, with more than 70 teams delivering their work, which proves the developed formula for international hands-on education activities with a huge adherence rate from students.

An overview of the nanosatellite educational ecosystem in Europe and the existing concurrent design tools is also presented to better define the value proposition of Nanostar, how it fits in the ecosystem, and the NSS's competitive advantage compared with existing tools. Finally, the paper draws conclusions about the potential of Nanostar for space education and proposes concrete strategies for the future, such as: the development of an academy and expert programs to provide updated knowledge on open-source concurrent design and engineering using the NSS tool, and the development of an official organizational structure.

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References

[1] Jorge B. Monteiro, A. Guerman, “Nanostar, a collaborative approach to nanosatellite education”, November 2020, Advances in the Astronautical Sciences 173, (AAS 20-226):289-296
[2] Nanostar Consortium, https://nanostarproject.eu/, (accessed 16.09.2021).
[3] J. D. Deaton, “CubeSats Changing The Way We Use Satellites - How and why are companies turning to them?”, The Innovation Enterprise, pp. 1–6, 2016
[4] A. Poghosyan and A. Golkar, “CubeSat evolution: Analyzing CubeSat capabilities for conducting science missions”, Prog. Aerospace Sciences., no. November, pp. 1–25, 2016
[5] Libre Space Foundation, https://libre.space/, (accessed 16.09.2021).
[6] Space Challenges, https://www.spaceedu.net/, (accessed 16.09.2021).
[7] Sputnix, https://sputnix.ru//, (accessed 16.09.2021).
[8] I. B. Tascón, “ESAT, The Hands-On Training Satellite”, The 7th Nano-Satellite Symposium, Kamchia, Bulgaria, 2016, October
[9] Arctic Astronautics, https://arcticastronautics.fi/, (accessed 16.09.2021).
[10] Orbital Astronautics, https://orbastro.com/, (accessed 16.09.2021).
[11] M. Yamazaki, T. Zengo, “HEPTA-Sat Training Program: International Knowledge Transfer Using Hands-on Type CubeSat Education”, The Hands-On Training Satellite”, SSC18-WKVIII-04, The 32nd Annual AIAA/USU Conference on Small Satellites, USA, 2018, August
[12] European Space Agency, CubeSats – Fly your Satellite, https://www.esa.int/Education/CubeSats_-_Fly_Your_Satellite, (accessed 16.09.2021).
[13] Amateur Radio in Space, AMSAT, CubeSat Simulator, https://www.amsat.org/product/amsat-cubesatsim-pcb/ (accessed 16.09.2021).
[14] Open Cosmos, https://www.open-cosmos.com/ (accessed 16.09.2021).
[15] D. Knoll, “Model-based processes and tools for concurrent conceptual design of space systems”, 2019, Skoltech Center of Space Research
[16] Valispace, https://www.valispace.com/ (accessed 16.09.2021).
[17] S. Bussche, M. Witzmann, L. Lindblad, “A Hardware Development Tool Stack for Future Space Exploration - Tool Selection Criteria”, 68th International Astronautical Congress, 2018
[18] OCDT - Open Concurrent Design Tool, https://ocdt.esa.int/, (accessed 16.09.2021).
[19] H. Schumann, H. Wendel, A. Braukhane, A. Berres, A. Gerndt, A. Schreiber, “Concurrent Systems Engineering in Aerospace: From Excel-based to Model Driven Design”, 8th Conference on Systems Engineering Research, 2010
[20] D. Knoll, A. Golkar, “Coordination method for concurrent design and a collaboration tool for parametric system models”, 7th International Conference on Systems & Concurrent Engineering for Space Applications, 2016
[21] T. Gateau, L. Senaneuch “Cubesat Subsystems Preliminary Design: Nanostar Software Suite (NSS) First Prototype”, Interreg Sudoe Nanostar, 2019
[22] P. Dente, E. Castanho, F. Rosa, F. Oliveira, G. Ribeiro, J. Benedicto, “Microsatellite Flyby to the Moon's South Pole”, 3rd Symposium on Space Educational Activities, Leicester, UK, 2019.