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Evaluation of the Learning Process of a Data-Driven Systems Engineering Methodology in a Workshop Environment

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Abstract

Since its official introduction by the International Council on Systems Engineering (INCOSE) in the "Systems Engineering Vision 2020" (2007), Model Based Systems Engineering (MBSE) has become a standard during the design process of complex systems and has brought about vast improvements compared to traditional, document-based engineering. Nevertheless, MBSE tools can still become complex, in an effort to tackle the many problems faced by systems engineers. One of the main issues remains the handling of data and its propagation throughout the design, as the underlying calculations of the models are not continuously executed and therefore consistency between models, documents and simulations is not assured. To tackle this and other issues, an emerging approach was conceived to work beside MBSE that has huge potential to reduce complexity of the design process, enhance collaboration and significantly decrease necessary learning time: Data Driven Systems Engineering (DDSE). With DDSE, engineering data and associated structures, links and connections constitute the foundation of the systems engineering process. Data is constantly updated, shared and accessible from all the people involved in the design, while integrating and updating simulations and documents. The design is not a stack of separated inanimate objects, but a dynamic living organism, where all the parts contribute to the project: with DDSE, MBSE can realise its full potential. With the rise of interest towards the use of satellites, and with the introduction of new actors, such as universities and other entities with limited access to previous designs and knowledge, it is necessary to produce a new software tool that fills the gap between the conceptual phase and the hardware design phase, allowing a clear view of the system for multiple users. This paper presents the main results of a workshop held for university students, to analyse their first impact with system engineering and with a newly defined browser-based software stack that is available to the engineers in this field. The research focuses on the comparison between DDSE and document based engineering during a case study, observing users' reactions and their learning process, and collecting opinions about the usage of the software. A more in depth analysis of the software stack was presented at the International Astronautical Congress (IAC) 2018 in the work entitled "A Hardware Development Tool Stack for Future Space Exploration - Tool Selection Criteria" (Lindblad et al., 2018).

Keywords: Data-driven, Systems engineering, Concurrent design, Education

Acronyms

API Application Programming Interface
DDSE Data Driven Systems Engineering
MBSE Model Based Systems Engineering

1. Introduction

Engineering concept and design methodologies have been constantly evolving, in a never-ending effort to address different challenges present in many engineering processes: lack of traceability and inconsistencies in documentation, lack of communication and understanding in the team are only a few.

This paper discusses how modern day technology, such as a web-based software stack, could bring the ultimate solution to these issues, in the form of a fully integrated engineering platform, a living organism that is constantly updated and shared between all the actors involved in the design process. In particular, it is presented and discussed how a team of students reacted and performed when presented with a systems engineering challenge to be solved using web-based software to collaborate concurrently in a limited time frame.

In section 2, the concepts of MBSE and DDSE are introduced; in section 3, the structure of the workshop is explained in detail. Finally, in sections 4, the conclusions of this research are drawn.

2. Background

Nowadays, engineering design processes tend to be more traceable and clearer, and this can be mainly attributed to the rising use of computers and software. What was done on paper, fax machines and blueprints, is now performed using a stack of software that allows the engineer to create a design and follow it from conception up to its operative life and disposal from the screen of the same personal computer.

Although IT has provided new, more effective means to guide engineers through the conception of new technologies and products, all the new available tools on the scene remain somehow scattered and hard to integrate into a whole, fluent, organic apparatus. Documents remain at the centre of the scene [1], and even when digitalised they keep presenting similar inconsistencies and traceability issues, due to the high number of versions and the regular use of mere copy-pasting to update them.

2.1 Model Based Systems Engineering

The past years have seen the birth and rise of the MBSE approach, which has been adopted by various entities, mainly in research settings and conceptual designs. MBSE is a methodology which takes advantage of software and moves the focus from documents to the "model", a central entity around which the project revolves. This approach tries to address the issues encountered in design processes such as [2]:

- communication and understandability of the process
- traceability and consistency of the models
- reduced time to market and reusability of model parts
- early validation and easier maintenance of the model

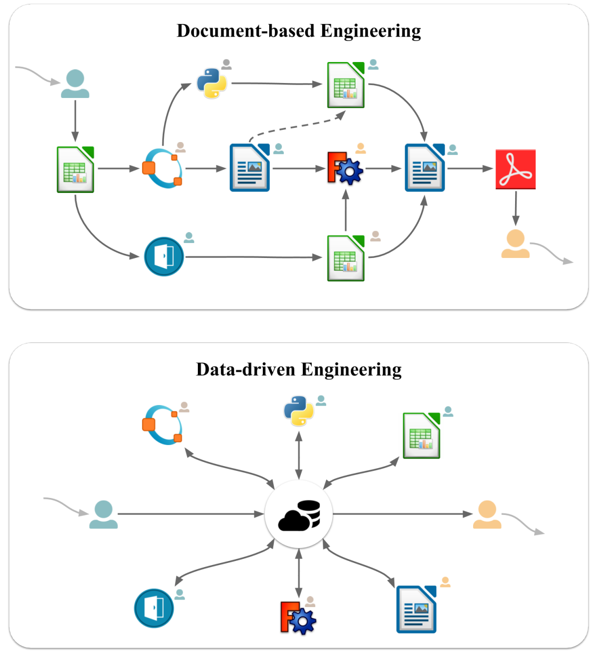

Figure 1: In traditional document-based engineering, data are shared in a manner that leaves space to errors, repetitions and use of non-updated values. Using DDSE, data is stored on the web, and the exchange is provided through Application Programming Interfaces (APIs) and it provides a single source of data, managing interactions and connections between users and sources.

Although companies attempt to switch to a model-based approach for systems engineering, MBSE is still not widely adopted by the industry [3]. This could be due to several factors, including the training required to use MBSE tools and learning the specific modelling language, which tends to not be user-friendly nor intuitive. Additionally, this approach doesn't sufficiently keep track of changes and usually the tools provided are not providing good communication between the project's stakeholders; these considerations emerge from the survey research that was presented by Lindblad et al. at the Systems & Concurrent Engineering for Space Applications Conference (SECESA) conference in 2018 [3].

On top of all this, MBSE has not yet taken further advantage of how present day information technology could make the systems engineering tools smarter. Systems which unify data sources and allow project managing and document generation in an efficient way without losing traceability could save companies great amounts of time, effort and money.

2.2 Data Driven Systems Engineering

DDSE is a new methodology that represents a potential next step in the development of design techniques, working with and complementing MBSE. It embraces new technologies, such as web interfaces and visualisation tools, which were not present at the time MBSE was conceived.

The term "Data-driven" refers to an approach where engineering design data and the associated connections constitute the foundation of the systems engineering process. The DDSE starts from the idea of collecting data into a single database, available concurrently to all engineers working on a certain product or project. Relations between the stored values are also taken into account as formulas. This way, it is possible to create a location for the data that becomes central in a project: documents are only one of the possible outputs, but the information is stored in a living database, constantly updated and monitored, with notification of instant changes and relationships between values. A software "stack" is now available for the modern engineer, to work in a fully integrated environment where links and servers substitute copy and paste and folders [4].

As it was outlined by Lindblad et al. in [3], in DDSE:

- consistency of engineering values allows the early usage of design models, helping simultaneously to detect inconsistencies, which cost time and money;
- automation is needed to increase the efficiency and reduce the possibility of errors, allowing to interact with several other software through APIs;
- traceability and transparency is fundamental for a methodology which uses multi-user tools, where data is continuously updated and re-used.
- optimisation, that comes into play once all connections between data are established, can help the engineer create a better version of the design.

Thanks to this, data-driven approach can bring a new, intuitive way to use model-based engineering, and pave the way to its full implementation in the industrial landscape.

3. The workshop

In this paper, the DDSE methodology is used in the context of a university workshop, in order to observe its capabilities and weaknesses when presented to a group of students that are asked to collaborate and work concurrently in a short time frame. The workshop was organised in five different occasions, and it saw the participation of more than a hundred students and young professionals. The sessions were held four times at the International Space University in Strasbourg, France, and one time at the Instituto Superior Técnico in Lisbon, Portugal.

3.1 Provided tools

The engineering tool mainly used by the students was the software Valispace®, which provided a repository for all the data shared by the students during the experiment. Valispace® is a web-based software tool where students could create system architectures of components and subcomponents, each with parameters that were linked between each other: on this platform, each value has a unique ID that can be referenced throughout the whole project. The students were also given a series of instructions, that guided them throughout the workshop.

3.2 Objectives and methods

The main interest behind the workshop was to qualitatively determine the impact new modern software has on the quality of the design and the time employed. In a very short time such as a 4-hour workshop, it was interesting to observe the reactions of users in front of a challenge, both in terms of engineering work and collaboration between members.

After an introduction on systems engineering, the workshop consists of a practical example of the engineering design process for space missions. The students are presented with a subject that has seen a growing interest in recent times: a Lunar surface base. The activity is composed of two main parts: one is dedicated to the "system of systems" architecture, and the other is focused on "system-level" design. The group of students, divided into teams of 4 to 6 people, are asked to collaborate to complete the workshop's assignments, described in a "engineering

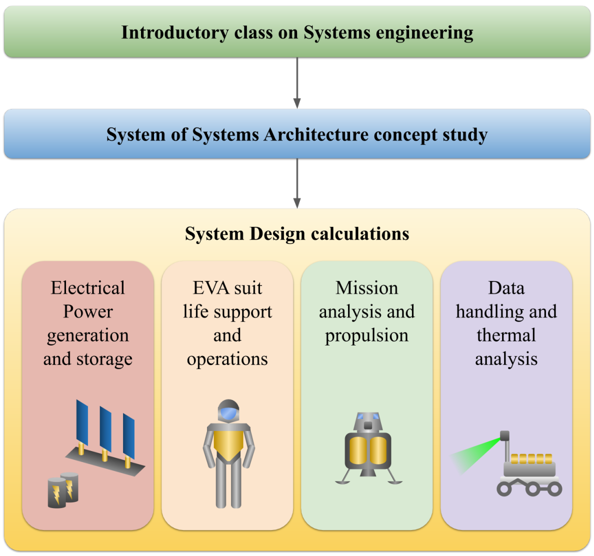

Figure 2: A schematic of the structure of the workshop.

manual". A representation of the workshop's structure is reported in figure 2.

The first part of the workshop is dedicated to the conception of a system of systems architecture, a fundamental part in the design of space missions. By focusing on an overall Lunar base architecture, this section is intended to stimulate the team members' creativity, inviting them to brainstorm with the help of whiteboards and other drawing tools. For the initial part of this section of the workshop, the web-based software is not strictly necessary, as students are invited to discuss the main objectives of their Moon mission, the role of crew members and a first concept of operations. Nevertheless, as output of this part they are asked to provide a product tree of the mission building blocks, producing very preliminary versions of their mass and power budgets. To perform this task, having a system engineering software proves useful as members can concurrently work on this architecture and produce a budget that uses by definition the most updated values.

In the second part, dedicated to sizing subsystems, the participants are asked to follow some procedures to complete the design process of some of the systems that will be part of a Lunar surface mission. In particular, the four interdependent systems are the Electrical Power Subsystem (EPS), a robotic rover, an Extra-Vehicular Activity (EVA) spacesuit, and a transfer vehicle from surface to orbit. Simple mathematical models are used, based on sizing procedures described in [5] and [6]. Inside each team, duties are distributed (the choice is left to the team members) and the procedure is carried out by inputting the provided data into the web-based software Valispace® and calculating new requested values using formulas written in the engineering manual. These formulas unequivocally link values inside each of the four systems, and between them as well, pressuring the team to communicate and collaborate. In one of the performed workshop sessions (with slightly extended time), the teams are given, once they reached the end of this part of the workshop, an update of system data and requirements. This obligates the responsible person to modify the input data for their mathematical models, and observe the outputs changing and propagating through their work and the other team members'.

3.3 Results

In each of the organised events, a qualitative evaluation of the workshop and of the software provided was performed by the organisers, collecting opinions throughout the experience, and in the form of an anonymous questionnaire, given at the end of the activity. The students were also required to fill a results one-pager, where the most updated values of main design data had to be copied. This allowed the organisers to verify the quality of the model and the level of collaboration that was implemented in each team: if links between values were not established, the values couldn't result as correct.

Students overall expressed positive opinions on the format chosen for the workshop, and some comments were helpful to bring modifications on the materials provided to improve the experience. All teams were able to perform the systems sizing section of the activity, producing results that were in most part correct: this result also depended on the background experience of each team member, which ranged from first year Bachelor students to graduate professionals. Due to their diverse knowledge, and their inexperience with the systems engineering approach, participants enjoyed the collaborative work, and the DDSE software was praised for its capability to easily share and modify data, creating and updating documentation at the same time.

Negative comments were referred mostly on the nature of the exercise, where not much space was left for

Table 1: Average votes given to the most relevant questions of the questionnaire, where 1 corresponds to "insufficient", and 5 to "excellent".

Question	Vote (1 - 5)
How was the experience, overall?	4.7
How would you define the provided material (documents, presentations)?	4.2
How would you define the staff assistance?	4.8
How useful was the DDSE software during the workshop?	4.2
Would you use the DDSE software again for your projects?	4.2
Would you suggest the DDSE software to your colleagues/employers?	4.3

creativity and the required operations resulted sometimes repetitive. This was mainly due to the short time available to hold the workshop: with a 4-hour dedicated session, the organisers agreed that the best option to convey the lessons was with a condensed and directed structure of the exercises. The DDSE software, by definition, requires an internet connection to communicate with the servers where data is safely stored: this brought some issues that were discussed with the staff present on site. In the space mission architecture part of the workshop, students appreciated the relevance of the subject of Lunar exploration, and were able to present interesting results, when considering the very reduced amount of time available to discuss.

From the results of the anonymous questionnaire handed out to all of the workshop participants, it was interesting to see that more than 80% of the students who answered the questionnaire gave the highest marks (corresponding to "very interesting") to the question "How was the experience overall?". More than 70% percent considered that the DDSE approach helped them collaborate and start to work very quickly: no time was needed to setup a concurrent design framework. In particular, the students reported that the DDSE software gave them an optimal overview of their project, since it allowed them to always visualise the most updated values, track changes and tackle errors. In table 1, the average answers to the most relevant questions are reported.

Between the most relevant answers to the question "What are the advantages, when compared to other software tools you know?", students appreciated the capability "to have all members of the project working at the same time" and the possibility of "creating documentation directly from the web-based interface", without having to copy and paste data. Moreover, they praised the ability "to have all the different parts and data of an engineering project in one shared workspace". The "reference-based interaction of the software" (creating a value once and using it easily throughout the rest of the project) and the "level of detail in each value" (like a systems that manages automatically units of measurement) were considered "essential and brilliant". The fact that when a value is changed "the effect ripples through your dependencies" really helped the team work concurrently on their design. It removed "some of the boring and repetitive parts" of using other software. Finally, the "capability to change automatically variables in the report" was considered very useful. Some students expressed interest in applying the DDSE methodology to their own university and personal projects, migrating from conventional software. Another interesting remark was made that such a web-based software made it easier to overcome language barriers, which are very common in greater engineering groups that work concurrently on the same project.

4. Conclusions

Introducing new methodologies in the engineering design process is difficult, as innovation finds a barrier in traditional methods and company heritage. Nevertheless, the advantages of concurrent design techniques have proved successful in supporting the design of complex systems, and are gaining a foothold in modern industry, although at a reduced pace [3].

New design methodologies, dynamical and flexible, seem likely to better adapt to the coming years of industrial progress; web-based platforms embrace the concepts of concurrency and real-time engineering, and will likely be the best environment to develop the projects of the future [4].

This paper reports on a workshop organised for students and professionals, with the main objective of observing the reactions of people when presented with a web-based engineering platform to be used to perform design calculations and concept studies. A workshop like this represents a learning experience for the participants, who become aware of what real-life cases might look like in a work and research environment. Meanwhile, the organisers had the opportunity to test the choice of the format of the workshop and improve it: small adjustments were made to the structure of the workshop and the questionnaire, to improve the experience of participants. Feedback on the DDSE software becomes extremely useful to refine the methodology and perfect the platform, which proved to overcome many difficulties that the participants declared to have with document-based engineering. Negative opinions were as valuable as positive ones, and will be used in future versions of this workshop.

The potential of such an intuitive way to see data is clear: students of today are the engineers of tomorrow, and they come from generations that have a completely different relationship with technology. A dynamic, visual tool could represent a boost to engineering design activities. The students also had the opportunity to grasp the size of complex space projects, and use their creativity to find innovative solutions.

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