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A TOOL TO SUPPORT CONCURRENT REVIEWING OF CONCURRENT ENGINEERING PRODUCTS

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INTRODUCTION

Concurrent Engineering involves an interdisciplinary collaboration which is essential to ensure that the system as a whole meets the mission objectives and that all subsystem interactions are thoroughly evaluated. The concurrent design process is specially important during the early phases of mission design, when it is crucial to do feasibility analysis and take early design decisions, which significantly impact the mission's success. Software tools together with the associated methodology are one of the main pillars for Concurrent Engineering, and most of the available tools for these early stages make use of a Model-Based System Engineering (MBSE) approach.

MBSE is becoming the preferred method over traditional document-centric approaches due to its flexible and interconnected nature, which allows for a more comprehensive representation of the system offering a structured methodology for its design and development. To achieve a consolidated implementation of the methodology, it is recommended to integrate this approach since the early stages of a project, and therefore, concurrent design teams are already making use of MBSE tools during the early phases of mission design. However, as space missions become increasingly complex, there is a critical need for effective tools and methodologies to support the development phases, not only helping engineers to define the system design, but also other stakeholders to review the status of the design at different stages. While MBSE has been integrated into certain domains and also into the review process, a standardised methodology that can be applied across the entire mission lifecycle has yet to be established.

One of the significant challenges in Concurrent Engineering is then the review process of the MBSE artefacts produced during the early phases as a result of concurrent design studies. These models serve as the foundation for decision making, but reviewing them can become a complex task specially for the stakeholders who might have not been involved in the design process. Moreover, reviewers often need to familiarise with new tools and modelling languages before being able to perform the review tasks.

To address the challenges that arise during the review of MBSE models, we have developed a web-based tool focused on the concurrent review process at early stages of the design, giving special attention to the Preliminary Requirements Reviews (PRR) and System Requirements Reviews (SRR). This paper presents the developed solution which aims to enhance the review process by providing advanced navigation and filtering options, real-time collaboration capabilities, and customizable views tailored to the needs of different domain experts. By integrating with existing MBSE tools, the application offers a seamless transition from design to review, allowing reviewers to concentrate on critical aspects of the system without being encumbered by technical complexities linked to the tools' usage.

The work presented in this paper is part of a Technology Development Element (TDE) programme activity which aimed to design, develop, and demonstrate a User Interface for Model Based System Engineering (MBSE) models, specifically focused on supporting model-based reviews in a concurrent environment. The prototype has been built by a consortium consisting of Starion Group, Human Design Group, ATG Europe, and IRT Saint Exupéry.

Following this introduction, the paper first presents the challenges identified for the review process of MBSE models, focused on performing concurrent reviews, and identifies the user needs to interact with digital system models. Then, the use case analysis is presented leading to the design and development of the solution that fulfils the user needs. The

structure and functionalities of the web application are presented in the following section, including a detailed description of the user journeys defined for the tool and the main aspects of the user interface. The validation process is then summarised to finally present the conclusions and the way forward for future related developments.

IDENTIFICATION OF USER NEEDS

Reviewers must verify that mission requirements are accurately translated into system specifications, assess the overall system design, and evaluate various risks and verification plans. The reviews are encompassing the system as a whole, including its subsystems and the interfaces between them. Therefore, the process requires the review from senior experts that belong to different domains, with knowledge in mission design and analysis. It is not feasible for one person to review the entire system design with sufficient rigour, as each domain of expertise requires specific verification and validation of design aspects. Jointly, the reviewers have to judge whether the system as a whole is feasible and likely to meet the mission objectives. To be able to assess this, it is critical that they do not only review the design from their domain perspective, but also develop a shared understanding of the overall performance of the system.

The primary obstacles encountered when implementing MBSE methodologies in industry can be attributed to the need of achieving a common understanding across diverse domains and levels of expertise, given that not all individuals are equally comfortable with the use of models. It is noteworthy that even within the community of advanced MBSE users, challenges have been identified in the interaction with the models and their views. This observation has been documented by Bucchiarone et al. [1] and Chami et al. [2]. Other challenges include the use of so-called ‘zombie models’ [3], which are models created and understood by domain experts, but which lack a connection and comprehension from other experts involved in the design process.

A considerable effort is required to guarantee that no key experts are lost in the MBSE process. These experts possess a critical knowledge of the system design, but they do not (yet) master the skills needed to create or even read MBSE models. Consequently, the overarching objective of this project was to investigate and develop a solution to facilitate the integration of model-based reviews into the existing lifecycle processes.

Challenges Specific to the Collaborative Review Process

The perspective of the reviewers on the work to be done may evolve as a consequence of the introduction of MBSE, which enables the design team to automatically verify and validate numerous aspects of the design. As a result, the focus of the review can shift from the identification of miscalculations and missing interfaces to an evaluation of the overall design trade-offs and solution directions.

Like system designers in a concurrent setting, reviewers bring expertise and past knowledge to the process, but this might also come with a specific focus on their domain. This specialization, while beneficial, could lead to several challenges:

1. Communication Barriers: experts from different domains may struggle to achieve a shared understanding of each other's concerns or even disagree on perceived discrepancies in the system design. Effective communication is critical to resolving these issues and defining a coherent and feasible system design.

2. Incomplete Reviews: the primary focus on domain-specific aspects can result in an incomplete review of the overall system. Critical interfaces between subsystems or key design considerations may be overlooked, which could potentially lead to integration issues at a later stage of the project.

3. Navigational Issues: senior experts may have extensive experience in their field but might be less familiar with MBSE tools. Navigating and interpreting complex models can present a significant challenge during the review, reducing the effectiveness and efficiency of the review process.

Use Case Definition and Analysis

To identify the user needs, a series of interviews and surveys were conducted with non-expert users of MBSE models. The objective was to analyse the needs of the users when interacting with a digital system model throughout the entire lifecycle of a space mission. Some stakeholders such as reviewers or domain experts may not require the ability to work directly on the models themselves, however, they still need to be able to ‘read’ the model in order to provide feedback and make decisions regarding the design.

The analysis has enabled the processing and classification of the pain points and needs identified by both expert and non-expert users of MBSE tools. This has resulted in the definition of multiple "personae" that correspond to the types of user profiles, which have been merged to create an overview of the needs and pain points of the primary users in this study, non-MBSE experts with a reviewing role. Having identified the main use cases for implementation, the next step was to

define the user and software requirements. The focus was on the review activities, and thus, the authoring and editing of models were not included in the initial scope of the project.

Following a thorough evaluation, the experts identified the most important use cases as those related to locating specific information within the model and presenting data tailored for review tasks, including budget calculations. It is essential that the solution facilitates collaboration in order to capture feedback on the model and provides guidance for novice users throughout the review process. The identification and classification of user needs for the project has already been presented at SECESA 2022 [4], and therefore will not be discussed in detail in this paper.

DESIGN AND DEVELOPMENT OF THE SOLUTION

Several tools and methodologies have been developed to support MBSE and concurrent engineering processes. These tools aim to facilitate model creation, review, and collaboration, addressing some of the challenges identified in this project. While existing tools offer multiple functionalities to facilitate the implementation of MBSE and enable teams to work together on models in real-time, there are still challenges in ensuring that all reviewers can effectively navigate and interpret the models. Before selecting the technology for the proposed solution and designing the software architecture, we have first assessed the state-of-the-art visualisation and navigation technologies, considering both hardware and software solutions.

Selection of the Technology

After analysing the existing solutions for collaborative modelling and comparing the available functionalities with the user needs identified, we have concluded that there is still room for improvement in terms of user experience and support for interdisciplinary collaboration. Most organisations and projects share the need of using tools that support real-time collaboration and information sharing among engineers and other stakeholders, but these tools are often too complex for beginners and lack user guidance. In the case of the review process, the tools should enable reviewers to track changes, provide feedback, and resolve discrepancies efficiently. Ideally, reviewers would not need to be experienced with the MBSE tools, methods or languages to perform these tasks and find the information in the models.

Based on the findings of the conducted evaluation, the addition of a visual dimension using other hardware technologies such as augmented reality or virtual reality would not resolve the inherent complexity of MBSE models. It is instead recommended that web-based 2D and 3D software frameworks are utilised in preference to other forms of technology. An evaluation of various MBSE tools was conducted to ascertain whether the existing features were sufficient to meet user requirements. However, none of the options offered a sufficient combination of guidance and collaborative features. One example is Cameo Collaborator Teamwork Cloud [5], which offers a variety of views for presentation and review features, such as comments and synchronisation with the model, but lacks guidance for following specific review processes and distributing tasks within a team. Further information on the technology evaluation process can be found in the project's public documentation [6].

The technology that was identified as being the most appropriate for meeting the project requirements was a web application. This would present the contents of the MBSE models to be reviewed in a format that was accessible and intuitively comprehensible to the user. The developed prototype provides an interface to the MBSE tool CDP4-COMET, which is used to present the ECSS-E-TM-10-25 models currently used by ESA to define early phase space system designs.

Scope and Structure of the Application

The developed prototype is the UI-DSM web application, which consists of a web-based user interface intended to present to users the system models designed in CDP4-COMET, simplifying the contents and density of information to allow them to perform and focus on the review. Users can review frozen iterations of the model created in CDP4-COMET, ensuring that all participants to a review are actually checking the same information. It currently focuses on the reviewing tasks of the first phases and milestones of the system engineering lifecycle, which are the Preliminary Requirements Review (PRR) and the System Requirements Review (SRR).

The review objectives serve as a point of reference when examining the data package, and thus, can also be applied when reviewing data generated when using model-based approaches. The web application lists the review objectives as defined in the Agency Projects Review Handbook [7], with detailed tasks derived for each review objective based on expert feedback. Specific views, settings, and filtering options were defined to facilitate the completion of these tasks for review data that is provided by the ECSS-TM-10-25 models.

The MBSE elements needed to be shown to reviewers in the application were identified and extracted from the models. These elements are then processed, classified and structured automatically according to the review task needs to ensure that reviewers find in each view the information they are looking for. The guidance and structure of the web application were discussed and iterated with expert reviewers to ensure full consistency with the already existing review processes.

A CDP4-COMET engineering model was also created to support the development and testing phases. The mission represented in this model is EnVision and the data has been extracted from the Phase 0 study performed at ESA's Concurrent Design Facility [8]. During this exercise, the project team has identified some inconsistencies between the mission and system design information required to be reviewed at these milestones, mainly at PRR and SRR, and the type of data usually considered and included in the MBSE models created at early stages. Some examples would be the detailed definition of interfaces or the proper classification of requirements including the verification method, the requirement type, and even the justification. These attributes are not always included in the MBSE model data. For the purpose of the project, this kind of information was created in the CDP4-COMET engineering model in addition to the main system design data extracted from the mission CDF report.

USER JOURNEYS AND USER INTERFACE

In addition to implementing all the identified views for the web application, the team also focused on designing a set of five user journeys based on the prototype structure, the overall review objectives and the user needs. The user interface was developed with the objective of fulfilling as many user requirements as possible, taking into account the limitations of the project and the time constraints. Given the fact that this is a prototype tool, it is envisaged that future fully operational web applications based on this one would incorporate additional functionalities and more advanced features.

User Journeys

The user journeys designed for the web application correspond to the following high level tasks:

- Inspect requirements completeness, flow down, and traceability
- Check requirement to function allocation completeness and adequacy
- Check functional to physical allocation completeness and adequacy
- Explore computed budgets and check if values meet the needs
- Investigate the architecture interfaces consistency and completeness

A generic user journey (Fig. 1) was defined to ensure that both the PRR and SRR objectives and their related tasks could be followed and performed. One of the main goals was to focus on offering an improved navigation guidance for reviewers, as opposed to typical MBSE modelling tools which typically allow users to move freely across the different views and parts of the user interface.

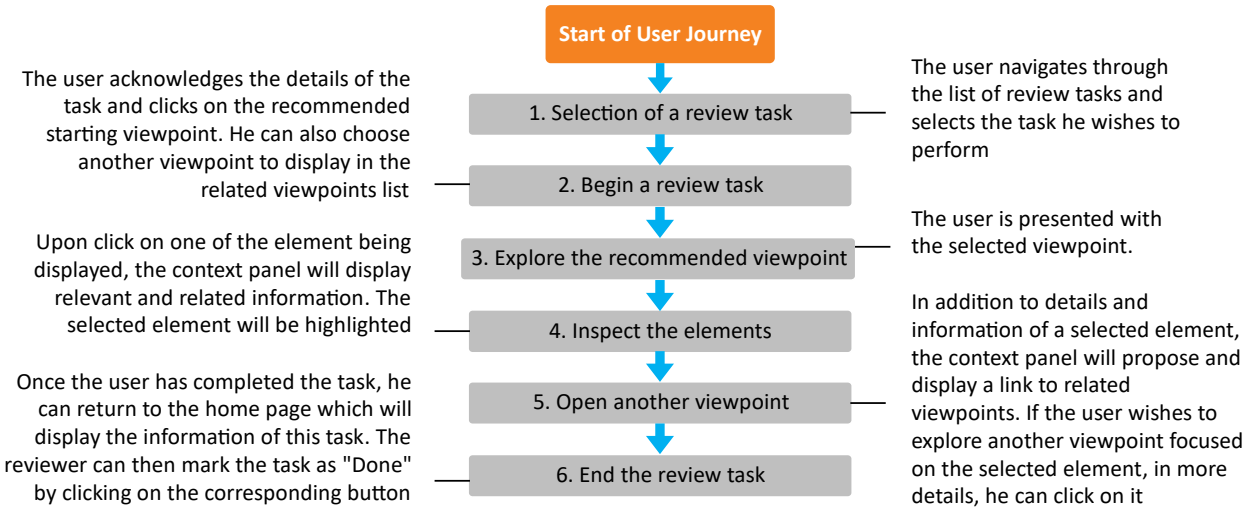

Fig. 1. Generic User Journey for the Web Application

The model review process for non-expert MBSE users is then simplified by guiding them though the different views according to the outlined review objectives. The generic user journey defines the main guidance provided to users in the tool and can be applied to the five high level tasks outlined at the beginning of this section. Even if those tasks were selected as having the highest priority for implementation, the structure and methodology of the developed solution support the completion of all the tasks derived from the PRR and SRR review objectives. It is also worth mentioning that besides the guidance provided by the tool, users have flexibility to follow different alternative steps during a review.

User Interface

The prototype developed has the layout and functions shown in Fig. 2. From the left hand side, the user can find the assigned review objective and associated tasks. Each task has one or more associated views, with one of them as a designated starting point. In the selected view the reviewer can execute the reviewing tasks, finding and filtering information relevant to accomplish the task in the main content section. For each aspect and element of the model, additional context information is provided in the context panel. This section can include descriptions, component attributes or properties, the owner of the selected element, and links to other model items such as traces to other requirements or the functions implemented by a product.

Related views are also presented on the right of the screen, where the element can be inspected in a different view to analyse the system and perform the task from another point of view. This helps users to get a better understanding of the design and of the links between the different modelling elements. The user can find issues in the model and report these as comments, and at the end of the process reviewers can mark a review task as done. It is possible to reply to previously created comments facilitating the discussion between the reviewing experts. The basic actions included in the prototype related to the commenting panel allow users to edit and delete comments, as well as to create additional links to other model elements.

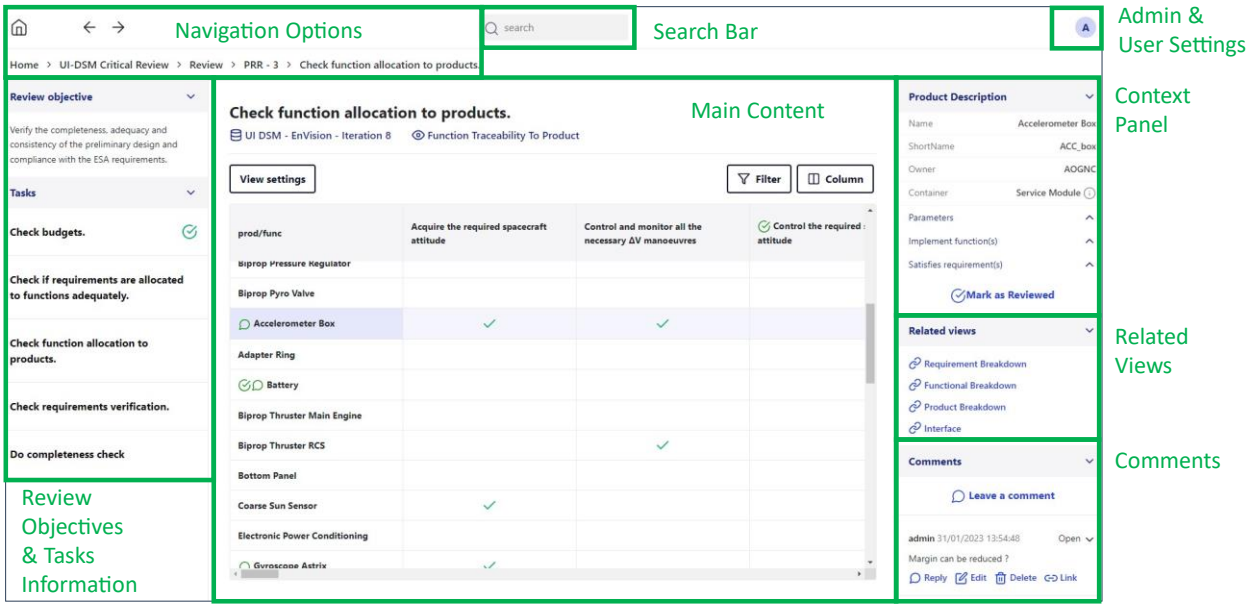

Fig. 2. Web Application features and layout

In the top centre a separate search bar allows the user to locate items that cannot be found in the present view. The information retrieved from the search is presented in a way that allows the user to select the desired view in which the searched element is to be displayed. The navigation options located in the top left of the screen facilitate the transition from one task to another and provide users with the necessary context to understand the stage of the review process to which they are currently contributing.

The right upper corner icon allows the user to navigate through projects and user settings, as well as access the admin functionalities. Finally, the prototype has basic review management and user administration functions. With the current version of the tool it is possible to add new users, assign specific review tasks to reviewers and see the progress of completion of the review process.

The project review objectives page is shown in Fig. 3. The number of tasks associated to the login user as well as the number of comments can be seen for each review objective. Upon selection of one review objective, the application displays the list of associated tasks, and each of these would take the user directly to the main view to perform the task. This facilitates the inspection of the MBSE model contents and guides the user through all the review process.

The complete list of comments from all users associated to a review is shown in the comment panel on the right of the screen. This list allows reviewers to get an overview of all comments raised on a model and review managers to help guide the discussion during the concurrent review process. It summarises all comments which remain open during a review, and when opening the comment the user is taken directly to the same view that the reviewer had when creating that comment.

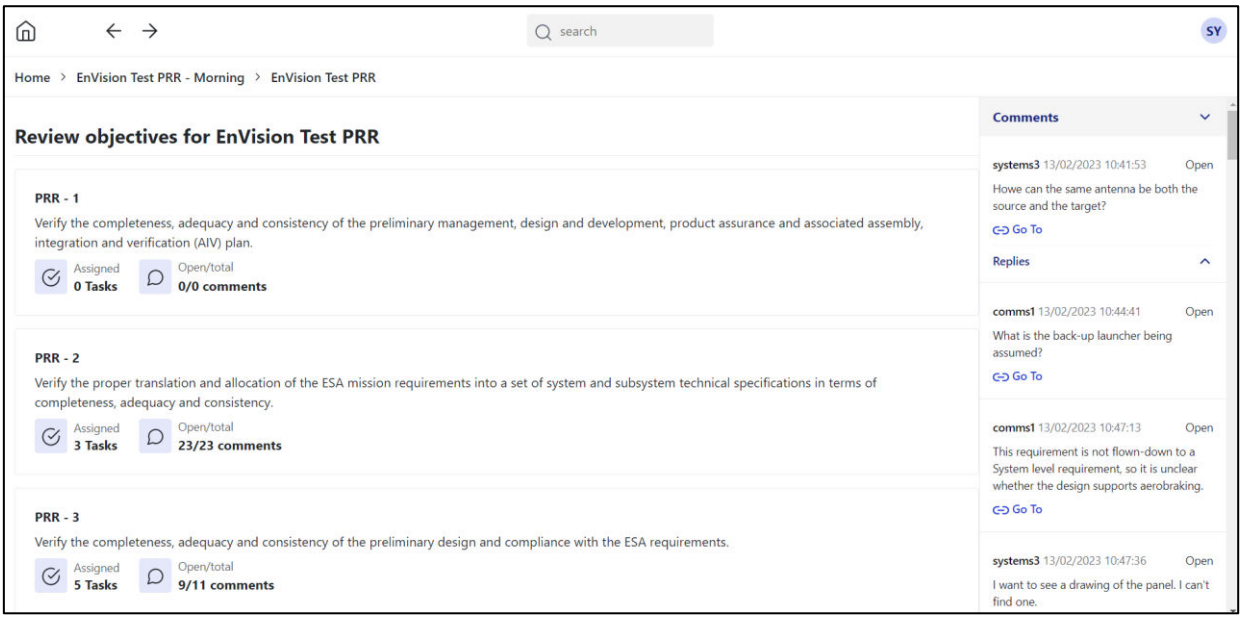

Fig. 3. Project Review Objectives page

Although there are multiple implemented views, there are 5 archetypical view-points:

- Breakdown, used for exploring requirement specifications, product trees or functional breakdowns.
- Traceability Matrix, used for checking relationships between the various modelling elements such as the link from requirements to functions, or from functions to components.
- Budget, where the budget calculations are displayed and users can export the generated report as pdf, word, etc.
- Interface and Physical Architecture Diagram, which shows first level interfaces of the selected component with information on the used ports, the source and target elements and the interface nature. It also allows users to navigate to higher level connections by clicking on the displayed components. The colour of the connecting lines defines the interface nature in the diagram and a legend is used to facilitate the interpretation of this kind of data.
- Context, this is the panel showing additional information on the selected element.

Examples of these views are shown in Fig. 4. The context panel is not shown as a dedicated view in this figure as it appears on the right side of the screen when additional context information about the selected model element needs to be displayed to the user.

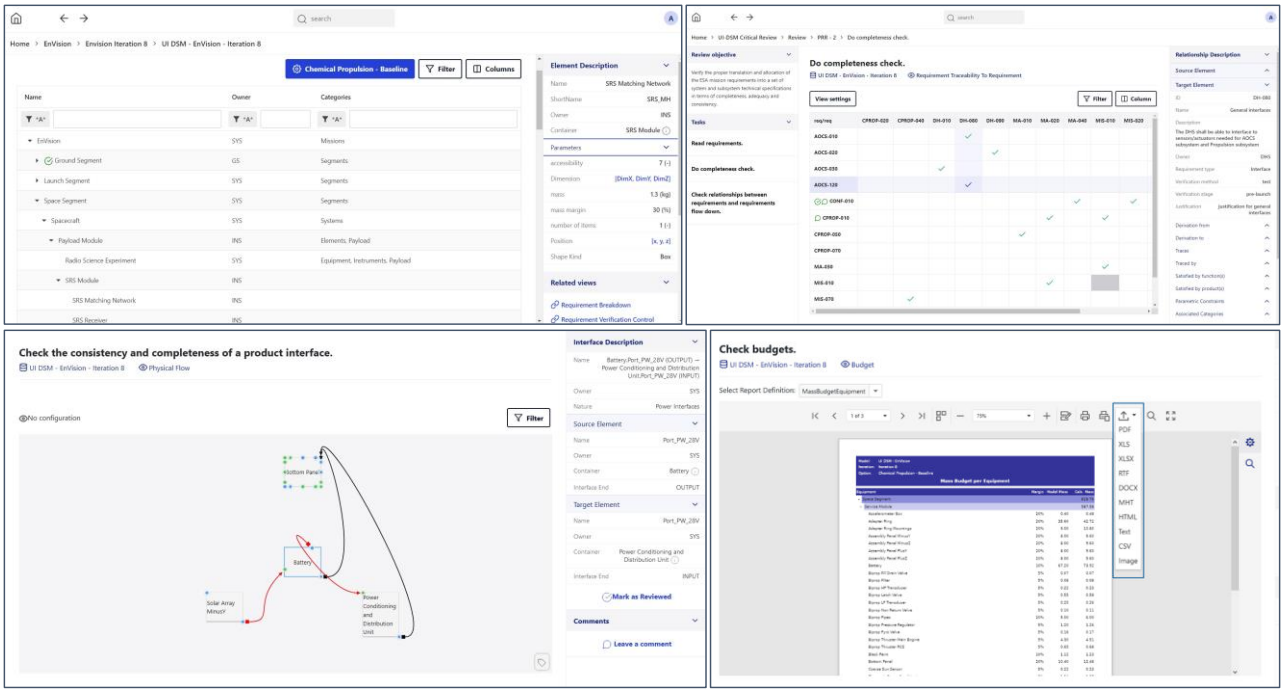

Fig. 4. Web Application views

VALIDATION

The developed solution was validated at ESA CDF with a selected group of potential users to evaluate the application and the user interaction in a realistic environment. A concurrent review exercise was performed as part of this validation plan. In this activity users were assigned to review tasks and had to check certain elements, links, and properties in the model, using the multiple navigation options to look for specific information and leaving comments where inconsistencies where found. Users were assigned different domains and they checked different parts of the model using the functionalities of the tool. An expert took the role of review manager and guided the users through a concurrent review process at the end of the exercise discussing the issues raised through the comments in real-time and looking for solutions or actions to fix them. Individual interviews were also organised after the session to obtain a more detailed analysis of the tool usability.

Among the results of this exercise, the team has assessed whether the main issues with traditional MBSE tools identified in the first phase of this project had been sufficiently addressed. Users identified key improvements related to issues typically found when using traditional MBSE tools, being the most important that users find now in the UI-DSM application the interface layout less clustered and the data models easier to understand.

We observed a wide variety of ways in which review objectives and tasks were completed and not all users searched for information in the same way. Therefore, it would be interesting to keep the flexibility that the application offers to perform tasks in different ways. However, this may affect the way information and views are presented and might have an impact on user guidance, so special attention must be paid to these points.

CONCLUSION AND WAY FORWARD

This project concluded in the first half of 2023 with the main objective of designing a solution that satisfied the needs of non-expert reviewers when interacting with a digital system model, and develop and validate it to TRL3. The developed prototype was designed to cover the identified user needs and to support the concurrent review of models during the initial phases of the design offering guidance to users. This section summarises the conclusions of the project.

It has been demonstrated that a web based application can offer guidance to MBSE users and help them find things in the models, even if they have not been involved in the modelling effort themselves. Despite this, the team has also identified indications of the reverse effect, as expert MBSE users/modellers find the guidance unpractical and would like to navigate the models more freely without restriction. It is important to acknowledge that reviewers are not typically involved in the design sessions and that it is not common for them to possess the necessary competence and independence with MBSE tools and methods that would enable them to explore the model contents and provide an objective and constructive review.

To facilitate efficient navigation within the model contents, MBSE models need to be highly interlinked. This process requires additional effort since model elements must be consistently linked, detailed and correctly classified. While such consistency serves multiple purposes in the context of MBSE and model integration, this level of detail is not yet common at early stages. The test model used in this project had to be extended for this purpose, and this could imply that the amount of rigour in the model exceeds the current practices. A balance between rigour and relevance is therefore critical in this aspect, as it is easy to ‘over structure’ the model for the sake of navigability.

The developed application includes basic functionalities needed for review management and for supporting the concurrent aspect of reviews in the context of MBSE methodologies. Examples of these features are the assignment of reviewing tasks to users, marking tasks as done and commenting on the model. In the same way that the design process benefits from using a concurrent approach, reviews performed concurrently can save time and facilitate the discussions between reviewers from different domains.

Moreover, users expect to find detailed diagrams in the review tool that are easy to understand, similar to system diagrams found in documents. However, creating intuitive diagrams is not yet an analytic effort that can be easily automated. Besides the technical challenge in this (auto-layout), good models also require abstraction to selectively display key aspects. Achieving consistent automation would require a complex ontology embedded in the model and the software.

Other state-of-the-art technologies could be also included in future versions of the developed solution. One example would be the integration of Artificial Intelligence (AI) by means of automated assistance when defining the requirements or other model elements. AI-driven features could be incorporated to assist reviewers in identifying potential issues, verifying model consistency, and generating insights. An example of a Digital Assistant including some of the required functionalities to support the modelling and reviewing tasks has been described in the paper “Design of New Space Missions with the Support of a Digital Assistant Focused on Systems Engineering Activities during the Early Design Phases” presented as well in this conference.

The current prototype supports a live connection to a CDP4-COMET server based on a frozen iteration. In the future the tool would need to be linked to a live model, seeing model updates directly in the tool. It should also enable to freeze iterations to perform reviews for key milestones and to compare progress or changes between iterations of the model. Furthermore, the application should also be able to support reviewing models coming from shared repositories, like the MBSE Hub, to include the review of information from different source models and to enable reviewers to also find inconsistencies between different interlinked models.

This paper has presented our experiences with developing, implementing and testing this tool focused on concurrent reviews performed at early stages. We have explored how concurrent reviewing can be improved through both technological advancements and process optimization. Future research and development efforts should try to fill in the identified issues and gaps to enhance the effectiveness of MBSE and concurrent engineering processes, leading to better-designed and more reliable space missions. One of the potential applications of the developed solution could be the review of New Space missions, as they could benefit from standardised processes to perform the review and acceptance of new space systems. The use of tools with more simplified user interfaces would improve and accelerate the review process, which can bring specific added value in the context of New Space. By addressing the unique challenges faced by reviewers in a concurrent engineering environment, we aim to contribute to more efficient review processes improving the quality and success of space missions.

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