Executive Summary

Augmented Reality for Concurrent Engineering Activities

Reference: LS-ARC-EXE-0001

Issue: A.01

Date: 12 April 2022

Contribution Log

Prepared by	Organization	Signature	Date	Issue	Rev.
Tajana Lucic	Lusospace		25 Mar 2022	A	00
Frederico Freitas	Lusospace		25 Mar 2022	A	00
Inês Cadilha	Lusospace		25 Mar 2022	A	00
Inês Cadilha	Lusospace		12 Apr 2022	A	01

Checked by	Organization	Signature	Date	Issue	Rev.
Filipe Tavares	Lusospace		25 Mar 2022	A	00
Inês Cadilha	Lusospace		12 Apr 2022	A	01

Approved by	Organization	Signature	Date	Issue	Rev.
Inês Cadilha	Lusospace		25 Mar 2022	A	00
Inês Cadilha	Lusospace		12 Apr 2022	A	01

Document History Log

Issue	Rev.	Date	Description of Changes
A	00	25 Mar 2022	First Issue
A	01	12 Apr 2022	Fixed typos: • "Congruent Engineering" substituted by "Concurrent Engineering" • Other minor typos

TABLE OF CONTENTS

1. Acronyms and Abbreviations

6DoF	Six Degrees of Freedom
API	Application Program Interface
AR	Augmented Reality
ARCE	Augmented Reality for Concurrent Engineering
CAD	Computer Assisted Design
CDF	Concurrent Design Facilities
CE	Concurrent Engineering
COTS	Commercial off-the-shelf
CSW	Critical Software, SA.
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
FoV	Field of View
GUI	General User Interface
HD	Hard Drive
HW	Hardware
LAN	Local Area Network
LOD	Level of Detail
LS	LusoSpace
NA	Non-Applicable
OCDT	Open Concurrent Design Tool
OS	Operative System
PC	Personal Computer
RD	Reference Document
SLAM	Simultaneous Localization and Mapping
SOW	Statement of Work
SPECS	Specifications
SW	Software
TRL	Technological Readiness Level
UX	User Experience
VPN	Virtual Private Network

2. Applicable and Reference Documents

2.1 Applicable Documents

The following documents contain applicable information:

[AD1] Statement of Work: Augmented Reality for Concurrent Engineering activities, ref.: ESA-TRP-TEC-SOW-015156, issue 1.0

[AD2] Detailed Proposal - Augmented Reality for Concurrent Engineering Activities, ref.: LS-MKT-ARE-0001

[AD3] AR for Concurrent Engineering Use Cases and Requirements [TN1], ref.: LS-ARC-TNO-0001

[AD4] AR for Concurrent Engineering Technical Specifications, Functional Architecture and Validation Plan [TN2], ref.: LS-ARC-TNO-0002

[AD5] AR for Concurrent Engineering - Final Report [TN3], Draft1, ref.: LS-ARC-TNO-0003

[AD6] AR for Concurrent Engineering – Validation Plan, ref.: LS-ARC-PLA-0001

[AD7] Not Used

[AD8] ECSS-E-ST-40C, "Space engineering - Software", 6 March 2009

[AD9] ECSS-Q-ST-80C, "Space product assurance – Software product assurance", 6 March 2009

[AD10] ECSS-E-TM-10-25A, Space engineering – Engineering design model data exchange (CDF), 20 October 2010. Annex A release 2.4.1, "SEIM-based data model for exchange ", available at http://www.purl.org/ecss/ecss-e-tm-10-25/annex-a, and Annex C "Web Services Interface", available at http://www.purl.org/ecss/ecss-e-tm-10-25/annex-c. Note: registration in the OCDT portal is required.

2.2 Reference Documents

There are no reference documents with applicable information.

3. Introduction

The ARCE activity was devoted to developing an Augmented Reality solution to be used in Concurrent Design Engineering processes, integrated with the OCDT specifications currently being used within the Concurrent Design Facility (CDF) at ESTEC.

The goal of ARCE is to augment the concurrent engineering design process currently on ESA CDF, allowing for better understanding and communication of the design models produced during multiple concurrent design sessions.

ARCE is easy to use and understand even for first-time users of *Mixed Reality* head-mounted display technology. It covers a range of features needed for a Concurrent engineering design exercise down to 10 features available to the users. All of these are on the augmented reality menu they can summon with the palm of their hand.

Figure 1 Two users running a design exercise at the CDF, ESTEC, and moving pieces of the 3D model while the presentation mode is active and visible on the projector canvas

Run in *Mixed Reality* on HoloLens 2, ARCE allows for state-of-the-art interaction using only the users' hands and no other external hand-held device. This allows for a comfortable experience and removes the problems of extreme fatigue, nausea, and vertigo sometimes associated with Virtual Reality.

4. Project Overview

4.1 Requirements Review and Application Definition

The development started by deriving low-level requirements from high-level requirements provided at the SOW. Several design options have been iterated early in the design phase to ensure the optimal design that will fulfil the need set by the high-level requirements and out-in-house user research. The storyboarded solution was presented to the users, discussed and accepted, after which it was wire framed and adapted to other technical and practical constraints.

With ARCE, users participate in concurrent engineering designs sessions powered by augmented reality. In these sessions, they can visualize and interact with 3D models derived from CAD models and the concurrent engineering model which comes from the OCDT server.

ARCE was designed to allow users to visualize a 3D model in real space and manipulate the parts of the 3D model, create new parts in scale, and position them to a preferred location on the 3D model. Users wearing a head-mounted device (Microsoft HoloLens 2) can simultaneously manipulate the pieces of the same 3D model while looking and moving parts that appear to be in the same place in real space. This manipulation encompasses moving around the system or parts of it through translation, rotation, or scaling. Users can also hide and unhide 3D parts of the model to manipulate parts within parts and have a better view of the object they are interested in. In addition, users can use a "ruler feature" to measure and demonstrate in scale distances and help guide new design decisions. ARCE allows the mapping of OCDT derived information to the constituent parts of the 3D model, meaning that information related to CE element properties and parameters can be accessed through the corresponding 3D part and vice-versa.

These elements and their parameters (weight, power consumption etc.) can be changed by accredited users and integrated into the CE model. Users can fill in the information regarding different technical disciplines and directly associate them with parts of the models.

These changes translate in the ability to compare design options live where users can see how changes impact the final budget of the equipment - for example, the total power need or the total weight of the satellite.

The users can also always use the 3D model configured at the start of the design session and visually compare the model's new and the start states.

The users that do not have the head-mounted device have the option to tune in to the session from their desktop application and watch the hand movements and the 3D model from the eyes of the presenter, which acts as a host. Most of the time, the users participating in the design exercise are in the same room. However, the implemented feature allows users who are not present to follow the changes.

4.2 Implementation

Agile development techniques were used from the beginning of the development to establish a pace across teams and frequently assess the delivered features. Another key reason for this choice was the fast-paced evolution AR technology was going through (and still is) that could be more easily managed if changes needed to be embraced rapidly during development.

Each application was divided into packages/modules, which were developed concurrently. The solution adopted and defined as part of the ARCE system:

ARCE Server

- **Integration with the OCDT**
    - Communication with the OCDT server, including reading and modifying the CE model.
- **Video streaming**
    - Implementation of the Real-Time Streaming Protocol to relay the Presentations video streams to the clients attending to them.
- **CE Engineering Manager**
    - Manages a local state of the CE model, keeping it updated for all the connected clients.
- **CAD Model Handler**
    - Loads and saves from and to STEP files. Handles conversion of models to a mesh representation.
- **Authentication**
    - Manages authentication of clients using their OCDT server credentials.
    - Frontend - UI/UX design and implementation of the server frontend.

ARCE Desktop

- **Presentation Module**
    - Functionality related to displaying the status of ongoing AR presentations and rendering them to the screen.
- **Frontend**
    - UI/UX design and implementation of the desktop application.
- **AR and Server Relaying**
    - Handles all exchanges from the server to the AR application and vice-versa.

ARCE AR Application

- **Interaction Components**
    - Definition and implementation of all common UI elements across all other functionalities and associated interactions
- **3D Model Interactions**
    - Display and manipulation of 3D models in virtual space.
- **CE Product Tree**
    - Display and interaction with data derived from the OCDT CE model.
    - Supporting Features
    - Functionalities such as budgets and virtual rulers that relate to both the 3D models and the CE design model.

4.3 Validation

The design exercise was executed on the **4th and 5th of March 2022 at the CDF, ESA ESTEC**. Two users were involved in the design exercise. The exercise followed a script that was agreed upon prior to the design exercise. The two users provided qualitative results with an average of 4.43/5 and a standard deviation of 0.63.

The total number of excellence scores was 13/28 in total. The items that scored an excellent mark from both users were assessing user experience with the menu and visibility of pieces moved from the perspective of a second user. The least scored item was connected to the difficulty of seeing 3D pieces when colored by their budget weight (red for heavy objects, green for light). There was no score lower than neutral (after adjusting the only inverted question).

Qualitatively both users expressed views of ARCE providing added value to the concurrent engineering design exercises. The benefits mentioned were the opportunity for multiple users to manipulate the same 3D object and other users to participate through their desktop application. A special note was made about the good usability and the simple layout that made ARCE easy to use.

An additional feature that was mentioned in the qualitative part of the questionnaire was the budget feature. The user has expressed that the use of that feature would provide an excellent extra opportunity for everybody in the concurrent design exercise to see the current state of the spacecraft they were designing.

5. Roadmap

The natural evolution of the ARCE system is, in the consortium's opinion, three-fold:

- **Overall raise of the TRL, from TRL 4 to TRL 6.** Such will encompass the improvement of system robustness and the implementation of improvements detected during the implementation of the current project and described in the lessons learned.

- **Integration and harmonization with third-party ESA developments.** As the ARCE project was developed, a new version of OCDT (V3) was deployed at the CDF. It was then announced that COMET would substitute OCDT and Concorde. On the other hand, the STEP – ECSS 10-25A mapping was implemented in parallel developments by ESA, which would be benefit ARCE. It is the natural step to integrate with such a system.

- **Adapt the ARCE system to newer, improved AR headsets.** The AR hardware market is in constant evolution and more advanced headsets, namely at the level of processing power, the field of view, weight, and autonomy are under development.

The roadmap presented in the final documentation focused on first two points, with a corresponding schedule and cost estimation.

6. Conclusions

Augmented Reality for Concurrent Engineering Activities (ARCE) is a set of SW tools developed by Lusospace (Server application, Desktop application, AR Interface) and its validating partner Critical Software that aims at implementing a system to assist multidisciplinary and distributed design teams by enabling visualization and editing of design models using Augmented Reality (AR) at the Concurrent Design Engineering Facility of ESTEC.

The consortium successfully implemented a software suite that allows for interacting with satellite 3D models (modifying absolute/relative positions and orientation of the model/components, evaluating dimensions) and engineering data (consulting and altering parameters, design options, budgets and issues, amongst others) in an AR environment.
The 3D model's position and orientation are shared amongst all users in the session, engineering data is synchronized between all AR users and OCDT, and a presentation mode is available for those users not wearing AR headsets. Several users from different disciplines can participate in the session (duly authorized and with corresponding permissions).

After development, testing was performed during the design exercise (two ESA experts who were frequent and active in concurrent design exercises) at ESTEC facilities at Noordwijk, Netherlands. The overall results were satisfying (4.5 out of 5 answers when questioned "I found that the ARCE application could add value to a concurrent engineering session").

A roadmap for future work, based on the findings of the project, was delivered. The roadmap focused on recommended steps to raise the TRL, from TRL 4 to TRL5/6 and integration and harmonization with third party ESA developments, and an estimation of schedule and effort was provided.

Considering all the achievements, the consortium regards the project as a success.