Virtual Reality-based Design for Complex Manufacturing Systems: the Case of an Electric Axles Production Line

DEI Doctoral Research Seminars - February 2nd 2022

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Engr. Vito Lazazzera

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  - Implementation of the VR approach
  - Evaluation of the VR approach from users' perspective
- Discussion of the main outcomes
- Conclusion and Future Works

Introduction

What is virtual reality?

Virtual reality (VR) is the term used to describe a digital artificial environment, based on computer graphics, that makes the human senses perceive and experience it as real.

Through the use of special devices, VR allows the users to immerse in a 3D reconstruction of the real environment, interacting within it.

VR device: HMD – Oculus Quest

Applications of Virtual Reality in Industry

In manufacturing, automotive engineering is one of the areas where virtual reality is used the most.

APPLICATION AREAS:

- Design
- Training assembly task
- Maintenance assessment
- Ergonomic assessment

- G. Lawson, D. Salanitri, B. Waterfield, Future directions for the development of virtual reality within an automotive manufacturer, Applied ergonomics 53 (2016)323–330
- N. Gavish, T. Guti´errez, S. Webel, J. Rodr´ıguez, M. Peveri, U. Bockholt, F. Tec-chia, Evaluating virtual reality and augmented reality training for industrial main-tenance and assembly tasks, Interactive Learning Environments 23 (6) (2015)778–798

Complex Manufacturing Systems (CMSs)

CMSs are defined ***complex*** because of their:

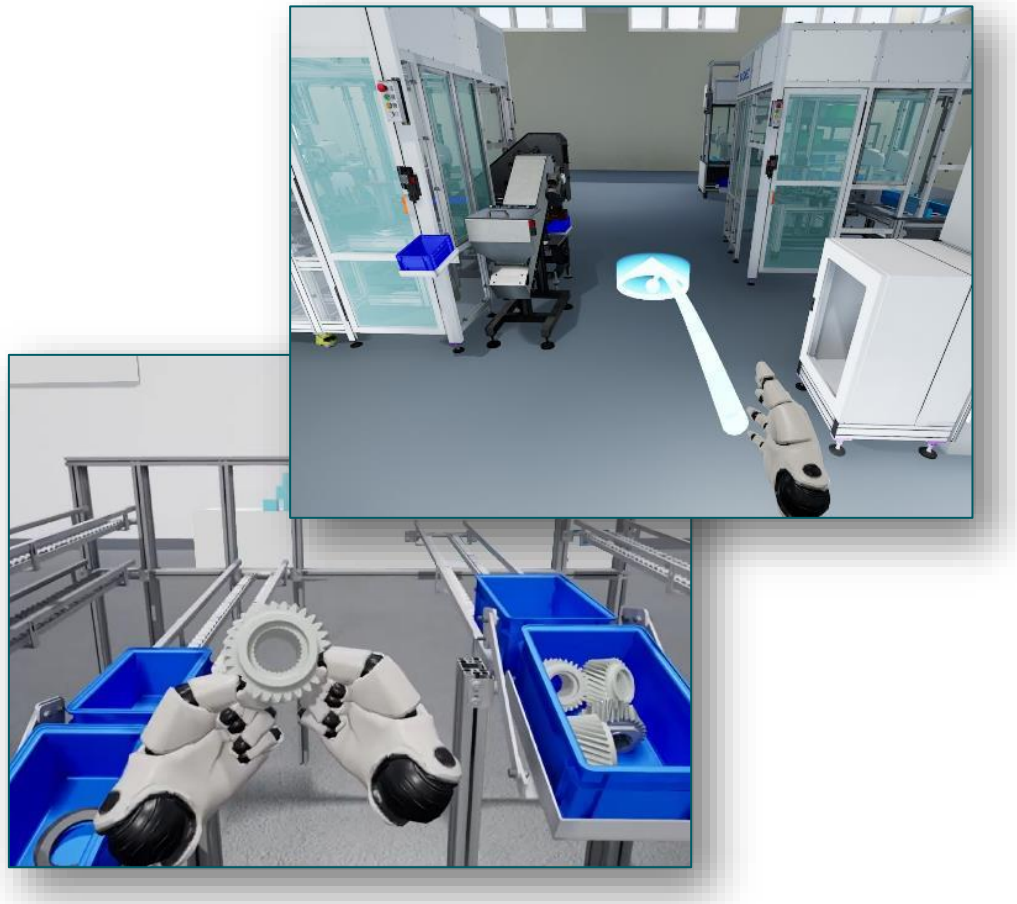
- Configuration
- Large-scale Layout
- Flexible machines
- System variety of components
- Implementation of human-robot and robot-robot collaboration

Virtual Reality in CMSs

VR provides a 3D interactive simulation of the CMS and supports the multidisciplinary design process, while facilitating the detection of issues in the early phase of the design process.

VR is emerging as a powerful tool to decrease design and production costs, while reducing the time needed between ***product conception*** and ***production.***

Which steps of the CMS design process can benefit from the use of VR?



- [c1] M. Gattullo, L. Dammacco, F. Ruospo, A. Evangelista, M. Fiorentino, J. Schmitt, A.E. Uva "Design preferences on Industrial Augmented Reality: a survey with potential technical writers", 2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2020), pp. 172-177.

Analysis of the CMS design process

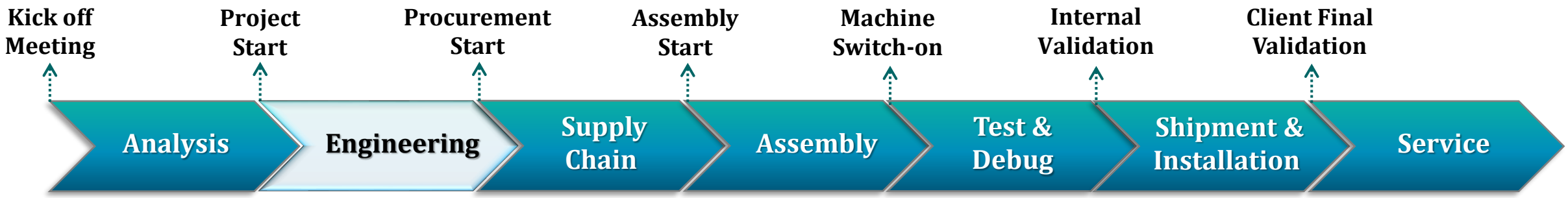
The CMS life cycle is typically organized into three phases:

The project acquisition is established after the acceptance of a commercial proposal customized for the client, thus allowing the company to set up *the CMS development process*.

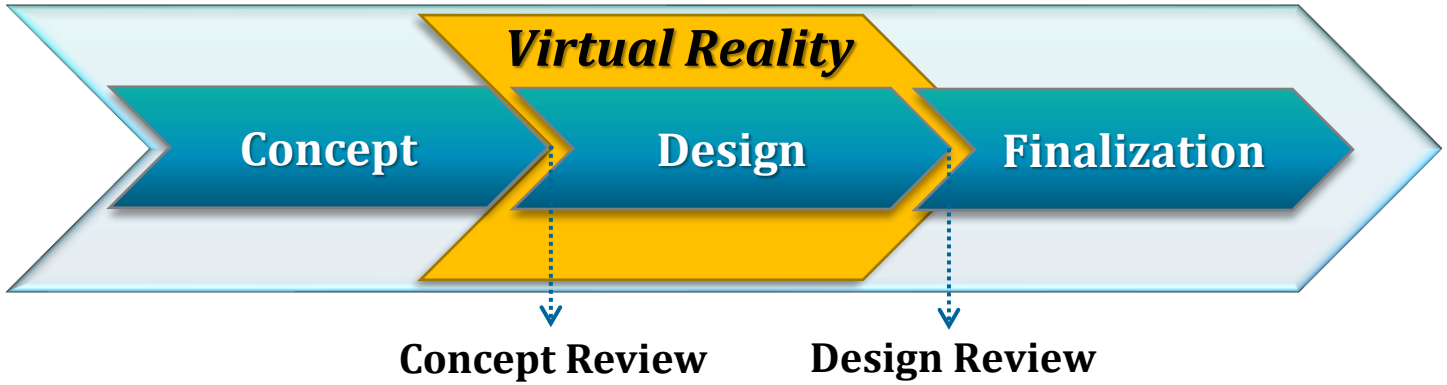
The after-sale service consists of following the customer in the system installation, first run, ramp-up, and maintenance.

- S. Gebhardt, S. Pick, H. Voet, J. Utsch, T. Al Khawli, U. Eppelt, R. Reinhard,C. B¨uscher, B. Hentschel, T. W. Kuhlen, Flapassist: How the integration of vrand visualization tools fosters the factory planning process, in: 2015 IEEE VirtualReality (VR), IEEE, 2015, pp. 181–182.
- J. Varaj˜ao, R. Colomo-Palacios, H. Silva, Iso 21500: 2012 and pmbok 5 processesin information systems project management, Computer Standards & Interfaces 50(2017) 216–222

Analysis of the CMS design process

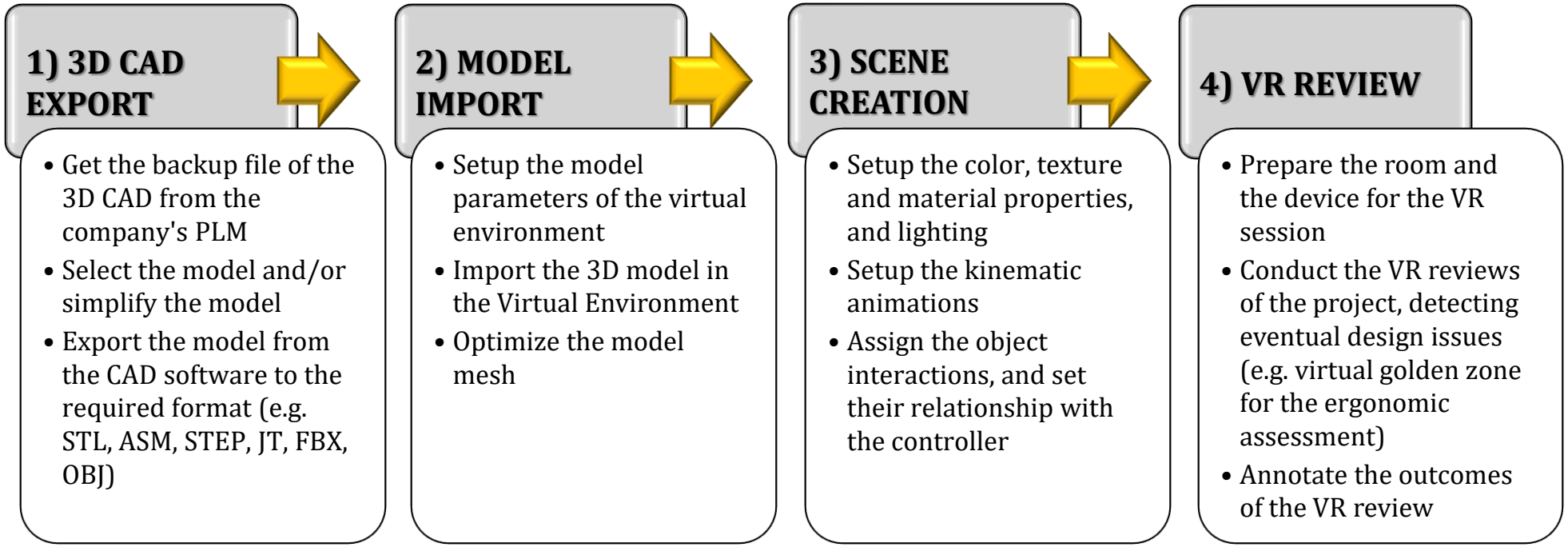


This work is specifically focused on the ***Engineering phase:***



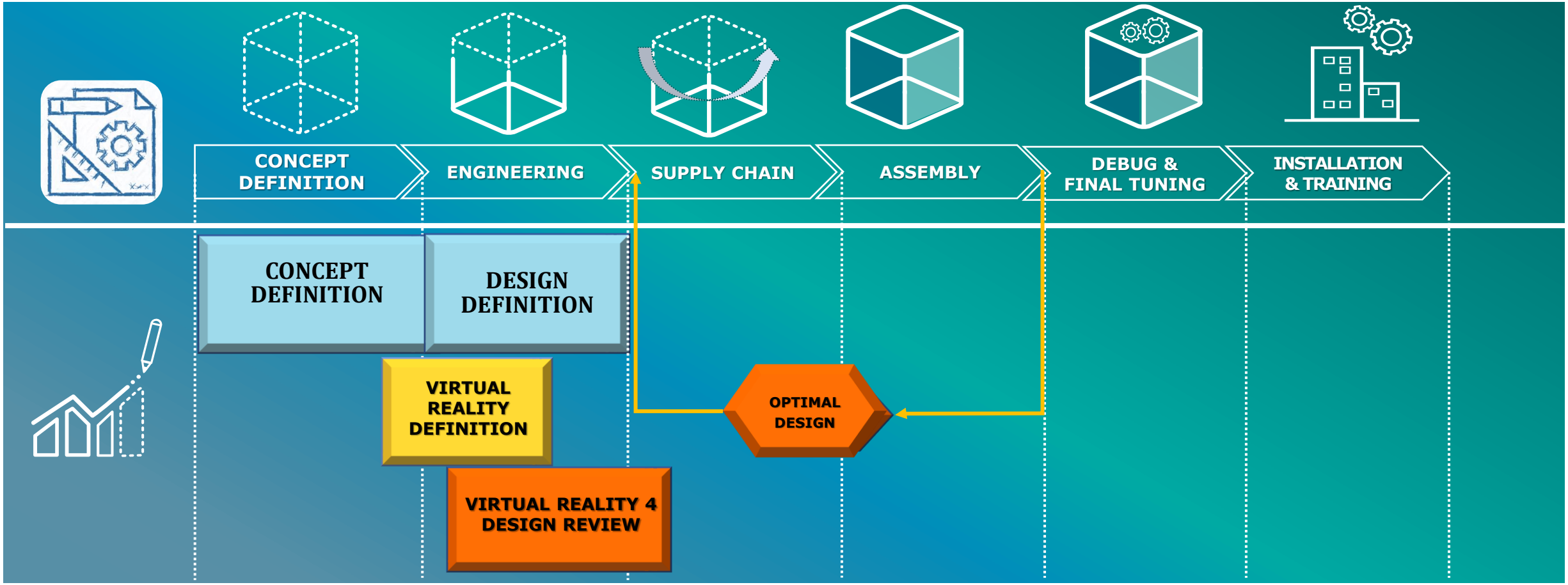
The proposed VR approach for the CMS design

VR approach that explains step-by-step the transition from CAD to VR:

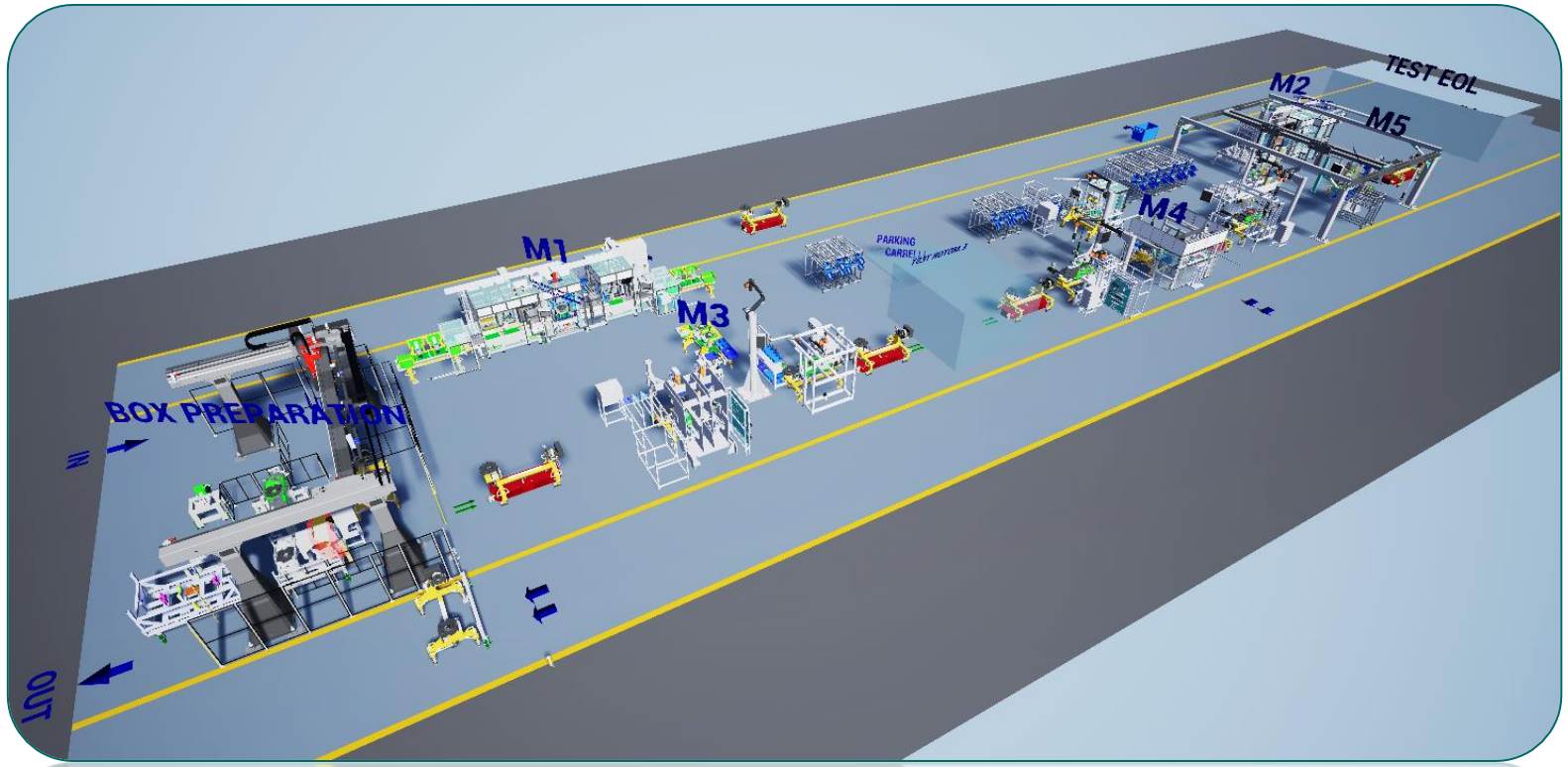


- [j1] L. Dammacco. R. Carli, M. Gattullo, M. Fiorentino, M. Dotoli, "*Design of Complex Manufacturing Systems Using Virtual Reality: a Novel Approach Applied to the Virtual Commissioning of a Production Line*" Computers in Industry **(submitted)**

Masmec use case: Presentation of the Electric Axles Production Line Design



Masmec use case: Presentation of the Electric Axles Production Line Design



The e-axle line extends on 1864 square meters:

- Subline (M1) - rotor and transmission preparation stations
- Mainline (M2-M5) - e-axle assembly stations
- Loading/Unloading area - box positioning on a cart
- Testing area at the end of the line (EOL)

Implementation of the VR approach

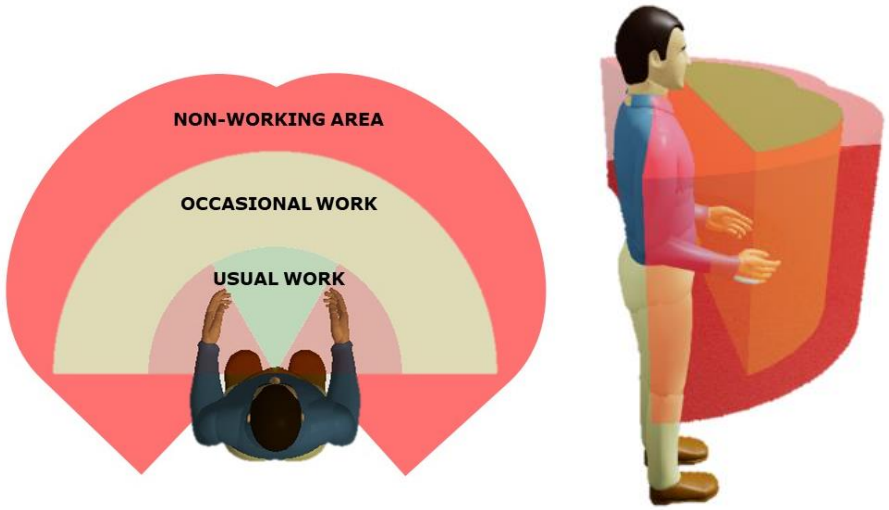
1) 3D CAD EXPORT

SIEMENS NX

windchill®

The CAD files were exported using the native NX, STEP, and JT formats, such as:

- Machine structure
- Conveyor
- Tools
- Equipment
- Gravity rack
- Manikin and golden zone



Manikin with golden zone

Implementation of the VR approach

2) MODEL IMPORT

UNREAL ENGINE

In general, getting CAD data into VR is a challenging task, but in the **Unreal** case, there is a plugin called ***Datasmith*** that supports different file formats.

This operation required the manual set up of all the main geometries by setting the *Light Mesh Options* and the *Geometry & Tasselation Options*.

Datasmith Import Options

Implementation of the VR approach

3) SCENE CREATION

UNREAL ENGINE

First the focus is on conveying a realistic experience by setting texture, material, color, and lighting according to the design specifications.

Example of the subline loaded in the VR scene, with windows, shadows, and artificial lighting.

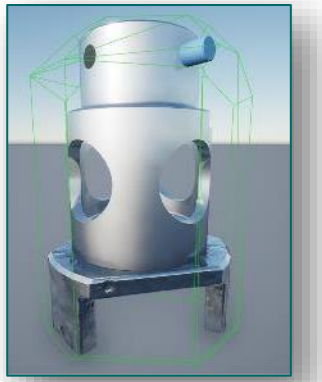
Implementation of the VR approach

3) SCENE CREATION

UNREAL ENGINE

Interaction tasks:

- Looking & Walking
- Teleport
- Touching & **Grabbing**



Simple collision

Detail of the press-fitting station showing the touching and grabbing of the rotor press-fitting tool.

Implementation of the VR approach

3) SCENE CREATION

UNREAL ENGINE

Interaction tasks:

- Looking & Walking
- Teleport
- Touching & **Grabbing**

Detail of the press-fitting station showing the touching and grabbing of the rotor press-fitting tool.

Other specific tasks:

- Virtual golden zone
- Virtual menu &Training with holograms

Implementation of the VR approach

4) VR REVIEW

- From 1 to 4 hours for each session
- About 20 people
- Teamwork:
  - Competence Leader
  - Project Manager
  - Project Engineer
  - Sales Manager
  - Designers

VR review session

Implementation of the VR approach

4) VR REVIEW

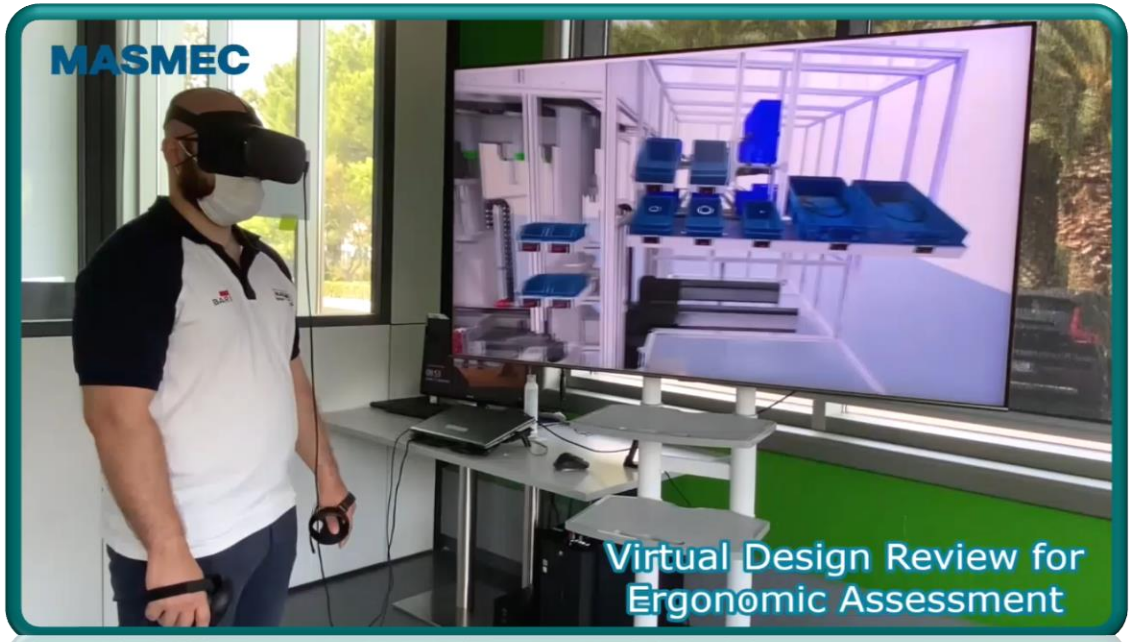
The scenarios centered around checking and evaluating the design issues using the following Specific tasks:

- Virtual golden zone
- Virtual menu & Training with holograms

VR review session

Virtual Golden Zone

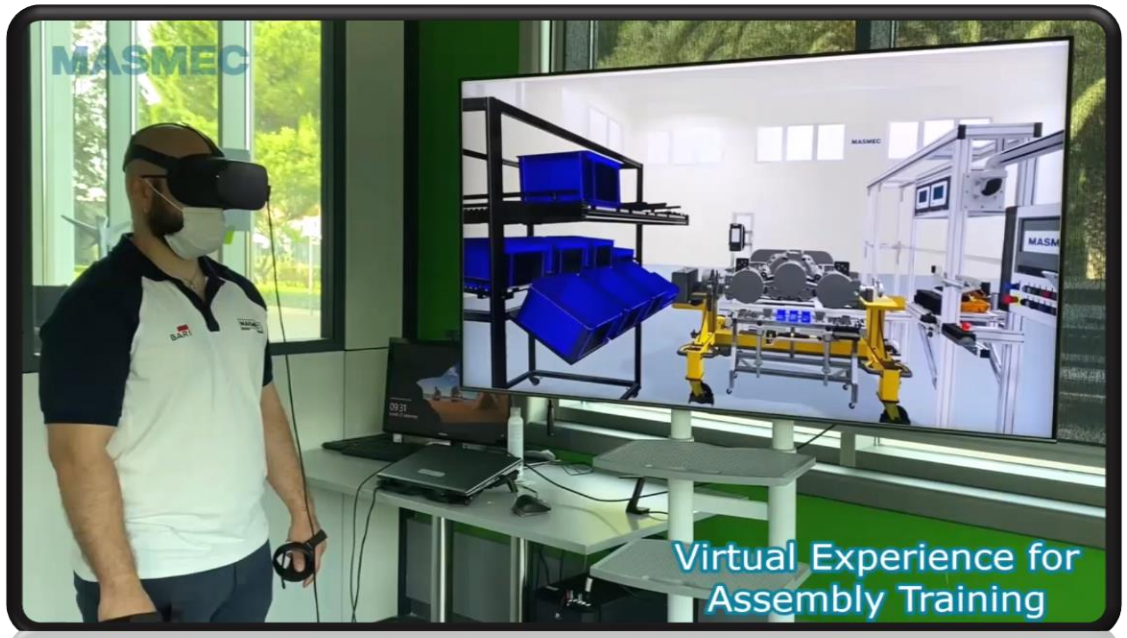
- During the VR reviews, the manikin and virtual golden zone were activated by the Oculus controller.
- The result was a semi-transparent volume with different colors around the manikin to point out the safety areas.



http://youtu.be/uoFPteauvxs

- [c2] L. Dammacco. R. Carli, M. Gattullo, M. Fiorentino, M. Dotoli , "*On the Use of Virtual Reality for Enhancing the Ergonomics of Complex Production Lines*" The International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing (JCM), 2022 **(submitted)**

Virtual Menu & Training with holograms



http://youtu.be/uoFPteauvxs

The VR reviews sessions was focused on:

- checking the *e-axle box rotation* on the cart with a virtual button
- mimicking the dressing operations based on the previously created interaction, the *hologram method*

Questionnaire

To verify the acceptance by professionals, in the e-axle CMS design project, the proposed VR approach was evaluated using a Microsoft Forms questionnaire.

- 23 users
- Avarage age of 36 years
- 2 females and 21 males
- 2 Competence Leaders, 2 Project Managers, 1 Project Engineer, 2 Technical Leaders, 7 Designers, 2 Assembly Leaders, and 7 others.

Questionnaire

Sections:

1. Familiarity with CAD-VR-Graphical User Interfaces (GUI)
2. Workload
3. VR usefulness and integration

Questionnaire

1. Familiarity with CAD-VR-Graphical User Interfaces (GUI):

   5-point Likert scale (ranging from 1 - No knowledge to 5 - Extreme knowledge)

Questionnaire

2. Workload: **NASA Task Load Index (TLX)**

- Mental Demand
- Physical demand
- Temporal demand
- Performance
- Effort
- Frustration

20-point Likert scale (ranging from 1 - Very Low to 20 - Very High)

Hypotheses:

- The work is less than the critical value of 50
- The workload is not affected by the frequency of VR use

Questionnaire

3. VR usefulness and integration:

5 point Likert scale (1 - Strongly disagree, 2 - Disagree, 3 - Neither agree nor disagree, 4 - Agree, and 5 - Strongly agree)

Questionnaire Results

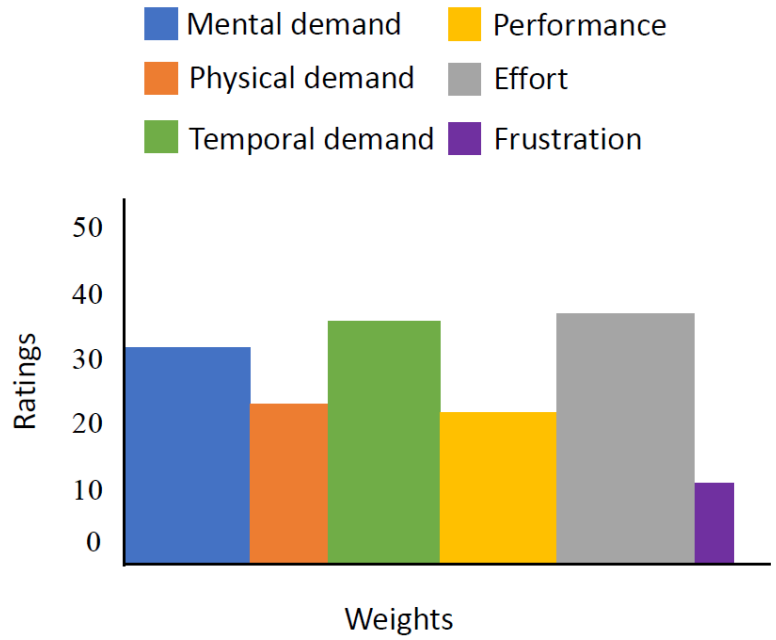
FAMILIARITY QUESTIONS

	No knowledge	Slight knowledge	Some knowledge	Moderate Knowledge	Extreme knowledge	Total replies
CAD	1	3	3	4	12	23
VR	5	4	6	6	2	23
GUI	7	5	2	4	5	23

- High level of familiarity with CAD
- Medium level of familiarity with VR tools
- Low level of familiarity with GUI

Questionnaire Results

WORKLOAD QUESTIONS



	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration
RATINGS Average score	29,6	21,1	35	20,4	35,9	9,8
WEIGHTS Average score	3,17	1,74	2,83	3,04	3,70	0,52

NASA TLX score of 30,14

Questionnaire Results

VR USEFULNESS AND INTEGRATION QUESTIONS

Questions	Median Score
VR can help through the product life cycle	5
VR has a positive effect on communication between departments.	4
VR enables me to see ergonomics flaws.	5
VR enables me to see design flaws.	4
VR enables me to see logical flaws.	4
Interacting with the components is fun.	5
Wearing the device is comfortable.	4
The interaction approach is intuitive.	4
I have been able to easily select and move parts of the power unit.	4
After removing the headset I felt dizzy.	2
Using VR I felt isolated from my team.	3

Discussion

- Questionnaire results showing that the presented VR approach significantly helped the development of CMS, especially during the design phase
- VR can help to identify ergonomics, design, and logical issues before the assembly phase
- All the team members obtained the same workload level that was also under the critical value of 50
- The interaction with the system component is fun and intuitive and wearing the device is comfortable.

Conclusion and Future Works

- ✓ The proposed VR design approach demonstrated to be effective in the CMS design, especially from the perspective of critical design aspects such as ergonomics and visibility.
- ✓ VR allowed a better organization of stations equipment and improved manual worker activities.
- ✓ VR demonstrated its advantages in improving project decision timing and communications between professionals of different sectors and skills, thanks to the new and visual language.
- ❑ The use of VR in the commercial proposal phase and the concept phase to obtain the expected result early and make important decisions on time.
- ❑ VR integration with discrete-event simulation models of CMS, aimed at optimizing their design and operation (e.g., layout of the plant, performance of the production lines, routes of AGVs).

THANK YOU FOR YOUR ATTENTION

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