Virtual Reality for the Evaluation of Human-Machine-Interface in Autonomous Vehicles

MASTER THESIS

Anna Aldea
MSc Design for Interaction

August, 2021

Contents

Appendix 1 : Project Brief

DESIGN FOR our future

TUDelft

IDE Master Graduation
Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

⚠ USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !   ⚠

family name	Aldea	4696
initials	A	given name	Anna
student number	5162386		
street & no.			
zipcode & city			
country			
phone			
email			

Your master programme (only select the options that apply to you):
IDE master(s): ◯ IPD   ☑ Dfl   ◯ SPD
2nd non-IDE master: _____
individual programme: __ - __ - __ (give date of approval)
honours programme: ◯ Honours Programme Master
specialisation / annotation: ◯ Medisign
◯ Tech. in Sustainable Design
◯ Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	Doris Aschenbrenner	dept. / section:	SDE
** mentor	Ilse van Zeumeren	dept. / section:	HCD
2nd mentor	Angelique Tinga		
	organisation:	SWOV	
	city: Den Haag	country:	Netherland

comments (optional)

⚠ Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

⚠ Second mentor only applies in case the assignment is hosted by an external organisation.

⚠ Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TUDelft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair   Doris Aschenbrenner   date __ - __ - __   signature

Dr. Doris Aschenbrenner
Digital unterschrieben von Dr. Doris Aschenbrenner Datum: 2021.02.10 14:44:38 +01'00'

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: __18__ EC

Of which, taking the conditional requirements into account, can be part of the exam programme __18__ EC

☑ YES   all 1st year master courses passed
◯ NO   missing 1st year master courses are:

List of electives obtained before the third semester without approval of the BoE

name J. J. de Bruin   date 10 - 02 - 2021   signature

J. J. de Bruin, SPA
Digitally signed by J. J. de Bruin, SPA Date: 2021.02.10 16:57:05 +01'00

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ☑ APPROVED   ◯ NOT APPROVED
Procedure: ☑ APPROVED   ◯ NOT APPROVED

- remark: no abbreviation in title, replace HMI with user interface

comments

name Monique von Morgen   date 16 - 02 - 2021   signature

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Initials & Name A   Aldea   4696   Student number 5162386
Title of Project Virtual Reality for the Evaluation of HMI in Autonomous Vehicles

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Personal Project Brief - IDE Master Graduation

TU Delft

Virtual Reality for the Evaluation of HMI in Autonomous Vehicles   project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple.
Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date   08 - 02 - 2021   15 - 07 - 2021   end date

INTRODUCTION **
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

In past years we have seen rapid developments in the field of automated transportation. However, there are several steps before full vehicle automation. The Society of Automotive Engineers (SAE) has defined six automation levels ranging from "no automation" (level 0), where the driver has full control and responsibility of the driving task, to "full automation" (level 5), where the driver does not need to be involved at any moment.
In the process of moving toward full vehicle automation (SAE level 5), there will be a period in which the driving task and responsibility will be shared between the driver and the autonomous vehicle (SAE level 2-4). This comes with new challenges such as mode confusion, reduced situational awareness, over-reliance and misuse, which can decrease the driver's performance ability and lead to an unsafe driving experience.

The MEDIATOR project, led by SWOV, the Dutch Institute of Road Safety Research, aims to tackle these issues through the development of an intelligent system that mediates the transition of control between the human driver and the autonomous vehicle. The mediating system will assess who is fittest to drive based on the driving context, the driver's state and the vehicle automation status.

The MEDIATOR project approaches the different levels of vehicle automation from a human-centred perspective, defining three driving modes: "Continuous Mediation" (CM) refers to the lowest levels of automation (SAE level 1-2), during which the driver is assisted in the driving task but must be alert at all times. "Driver in Stand By" (SB) is consistent with automation levels (SAE level 3-4) during which the automation can reliably take-over control for short periods of time. In these moments the driver can perform secondary tasks but must be ready to take-over the driving task on short notice. Finally, "Time to Sleep" (TtS) is a higher automation level (SAE level 4), which allows the driver to dedicate longer periods of time to other activities before he will be asked to take-over control of the vehicle.

The Human-Machine Interface (HMI) plays an important role in guaranteeing a pleasant user experience, as well as the safe and comfortable transition between driving states. Several HMI concepts are being developed within the MEDIATOR project. In order to converge towards a final HMI prototype, the concepts must be evaluated and iterated on. In this iterative process arises a need for a tool that can facilitate the testing process of the different HMI components in a rapid and reliable manner.
Virtual Reality (VR) provides an opportunity in the area of design evaluation, as it allows designers to rapidly implement digital prototypes in an immersive virtual environment, in which participants can interact with the different design elements.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

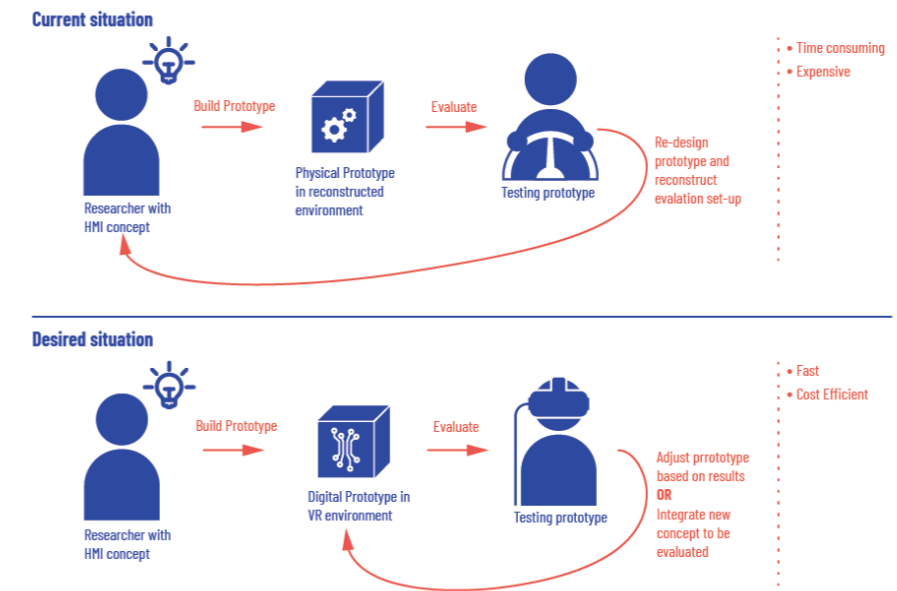**T**U Delft

introduction (continued): space for images

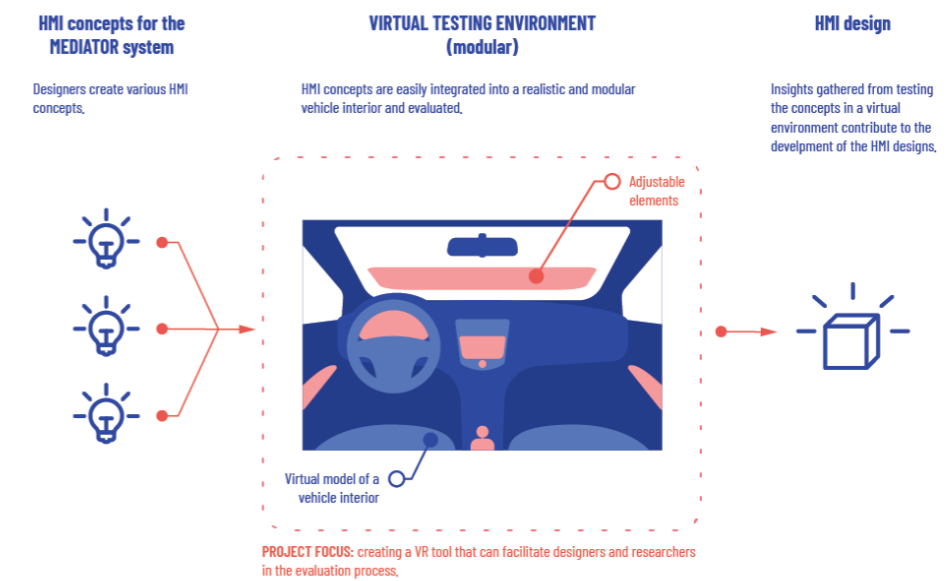image / figure 1:   Current and Desired Situation

image / figure 2:   Envisioned Solution Space

Personal Project Brief - IDE Master Graduation

*TU*Delft

PROBLEM DEFINITION **
Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Within the MEDIATOR project, a holistic HMI is being developed, which is multimodal and involves several parts of the vehicle's interior. In order to properly evaluate the different HMI elements, participants should experience a realistic usage scenario and be immersed in the context. As it is difficult to bring the evaluation of the HMI on the road in the initial evaluation stages, an alternative solution is needed. Simulating the context (interior of the vehicle) and situation (traffic conditions) in a Virtual Reality environment provides an opportunity for testing HMI elements in context and as a holistic design, rather than as separate elements.

Implementing designs in a VR environment allows for a rapid evaluation of HMI concepts, without the need to construct physical interactive prototypes, which takes more time and effort. Therefore, more concept iterations can also be tested and compared during the design process. Furthermore, using VR as a tool for evaluating user experience provides clear advantages compared to other digital evaluation methods that are currently used, such as animations which simulate a usage scenario. In a virtual environment, participants have a more immersive experience, as the entire interior of the car and several elements of the HMI can be simulated at once.
By creating a tool which allows researchers to test their designs in the context, simulated through VR, I can aid them in conducting quick and reliable experiments.

With the development of more capable and cheaper headsets, VR technology is becoming more accessible for applications in various fields, including design. Game development platforms such as Unity 3D and the available resources allow designers to create VR applications quickly and even with minimal coding knowledge. Digital prototyping also allows for a quick iterative process as applications can easily be improved upon and adjusted without the need to create an entirely new prototype.

ASSIGNMENT **
State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The goal of this project is to facilitate the design evaluation process of existing and new HMI designs created within the MEDIATOR project, through the use of Virtual Reality. A VR tool will be developed, aiming to simulate a realistic use context and capture a holistic user experience.

After researching the specific requirements for the testing of the HMI elements within the context of the MEDIATOR project as well as the advantages and limitations of using VR for conducting design evaluation, I aim to create a VR tool that will facilitate researchers and designers in this process.
Using Unity 3D a virtual reality environment simulating the interior of a vehicle will be created, inside which different existing HMI designs can be easily implemented and tested by the research team. A solution could be to create a modular model of the vehicle, in which different parts of the interior can be changed to include various elements of the HMI, as needed. In this process, small adjustments could be made to the existing elements with regards to their position in the vehicle and lighting.
Furthermore, I will explore how this VR tool can be easily adopted by the MEDIATOR research and design teams and, if needed, develop supporting materials, such as a usage guide.

This solution will allow researchers and designers to evaluate existing HMI concepts in a rapid and effective manner and gain valuable insights about the use of designs in context, which will contribute to the further development of the HMI.

PLANNING AND APPROACH **
Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date   8 - 2 - 2021   15 - 7 - 2021   end date
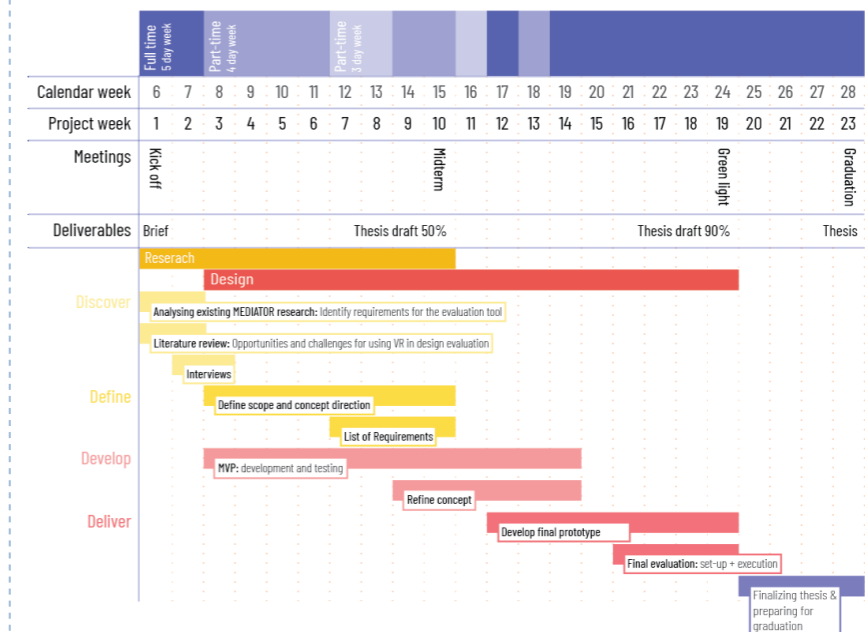
This project will be structured based on the Double Diamond model and devised into four stages of research and design:

Discover: The first phase of the assignment will be focused on research and understanding the context in which the evaluation tool will be used and its requirements, as well as exploring the possibilities and limitations of using VR as a tool for design evaluation.

Define: In the second phase I will define the challenges and frame the areas of opportunity, converging towards a final concept that meets the requirements of the stakeholders. A list of requirements for the final design will be created in this stage.

Develop: Based on the initial findings I will start iterating on the design through the use of MVP (Minimal Viable Product) which will be tested in order to identify requirements and points of improvement. Results of the initial tests will inform the previous phase and help define the scope of the project.

Deliver: In the final phase the VR environment will be improved and evaluated with the main stakeholders.

Finally, the results of the four stages will be synthesized in the graduation thesis.

Personal Project Brief - IDE Master Graduation

$\widehat{TU}$Delft

MOTIVATION AND PERSONAL AMBITIONS
Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your
MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed.
Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives
of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a
specific tool and/or methodology, ... Stick to no more than five ambitions.

My interest in tackling this project stems from the topic's relevance and complexity, which makes the design process
both engaging and challenging.
By conducting this project I aim to prove the research and conceptualization abilities that I have acquired thus far, but
also to improve my prototyping and evaluation skills.

Interactive prototyping and Virtual Reality development are skills that I am personally interested in learning, as I believe
they are a good addition to an interaction designer's skill set. During the past years I have had the opportunity to
develop a number of interactive prototypes and experiment with tools such as Unity and I look forward to continuing
on this path.

During the course of my studies at the TUDelft I have regretted not having been able to perfect my evaluation skills.
This was mainly due to the unexpected lock-down, which reduced our chances of conducting user tests face to face
and/or in context. In this project, I aim to create a more professional evaluation set-up and improve my ability.

Despite the ongoing restrictions caused by COVID-19, I am confident that, with the support of fellow graduating
students and my supervisory team, I can overcome the challenges, both personal and related to the project, that
might arise during this time.

FINAL COMMENTS
In case your project brief needs final comments, please add any information you think is relevant.

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Initials & Name A   Aldea   4696   Student number 5162386

Title of Project   Virtual Reality for the Evaluation of HMI in Autonomous Vehicles

Appendix 2 : VR Evaluation Forms

This form was used to structure insights regarding the requirements for the evaluation of the Mediator HMI using a VR prototype.

The forms were completed following an interview with the designer of the HMI, and used as a reference for the ideation of MVP1 and MVP2.

VR EVALUATION SETUP FORM

Mediator HMI concept:

Concept description:

Research Question(s):

Goal of the evaluation:

Mediator HMI concept:

In the following section include a visualisation of the design(s).

Mediator HMI concept:

User:
Please describe the task(s) that participants must perform during the evaluation. What is the goal of each task?
What are the needs of the user when interacting with the prototype?

Context:
Please describe the context of use and environment in which the design will be used.
Which contextual and environmental aspects can affect the experience and interaction with the prototype?

Data:
What type of data and information must be collected for the evaluation of the design(s)?

Appendix 3 : MVP 1 Evaluation Materials

For the evaluation of MVP1 participants were asked to answer both questions related to the HMI design, after each scene, and their experience with the VR application, after completing the experiment.

Questionnaire Scene 1 & 2

1. Can you explain what happened in the scene?
   a. What does the length of the dashboard lighting strip communicate?
   b. What does the flickering of the lighting communicate?
   c. What does the colour of the lights indicate?
2. On a scale from 1-5 how would you rate the visibility of the LED strip on the lower LED lighting (steering wheel, foot compartment and shift stick) with no animation?
3. On a scale from 1-5 how would you rate the visibility of the LED strip on the lower LED lighting (steering wheel, foot compartment and shift stick) while flickering?
4. Was the flickering lighting too distracting?

Comparison
1. On a scale from 1-5 how would you rate the visibility of the LED strip on the dashboard with no animation?
2. On a scale from 1-5 how would you rate the visibility of the LED strips on the A-pillars with no animation?
3. On a scale from 1-5 how would you rate the visibility of the LED strip on the dashboard when it started decreasing?
   a. Did you notice the change right away?
4. On a scale from 1-5 how would you rate the visibility of the LED strips on the A-pillars when it started decreasing?
   a. Did you notice the change right away?

Observation Scene 1 & 2

1	
When the lights first flash, indicating a change in driving mode the participant is alerted:	YES / NO
Indicate the reaction of the participant to the flickering. What does he/she say and do?	
2	
The participant notices the dashboard/A-pillar strips are decreasing:	YES / NO
What does the participant do after noticing the change? Where does he/she look?	
3	
Does the participant become alert/focused as the LED strip(s) decrease, indicating an imminent change in driving mode?	YES / NO
What does the participant do in that moment? Does he/she express understanding that there will be a change in driving mode?	

Questionnaire Scene 3

1. Can you explain what happened in the scene?
   a. Can you explain what happened to the LED strip placed on the dashboard?
      What did it communicate at that moment?
2. On a scale from 1-5 how visible were the changes in the length of the LED strip on the dashboard?

Observation Scene 3

1	
When the lights first flash, indicating a change in driving mode the participant is alerted:	YES / NO
Indicate the reaction of the participant to the flickering. What does he/she say and do?	
2	
The participant notices the dashboard strip is decreasing, remaining in their 30° cone vision and changing colour	YES / NO
What does the participant do after noticing the change? Where does he/she look?	
3	
Is the participant focused on the road/vigilant when the dashboard strip shows little time budget?	YES / NO
What does the participant do in that moment? Does he/she express understanding that there will be a change in driving mode?	

VR Prototype 1: performance test questionnaire

VR specific:

1. On a scale from 1-5, how **realistic** does the environment look?
   a. What would you change to make the scene more realistic?
2. On a scale of 1-5, how immersed do you feel in the space?
3. Do the elements of the environment feel "tangible"?
4. Are you able to determine your position in the space?
5. How does the **scale of the interior of the vehicle** compare to a real one?
6. Does your movement feel realistic?
7. On a scale from 1-5 how comfortable was the experience?
   a. Have you experienced motion sickness or disorientation?

HMI related:

1. Were you able to identify the lighting elements in the space? Rate the visibility of each element on a scale from 1-5
   a. Dashboard LED strip
   b. A-pillar LED strips
   c. Steering wheel lighting
   d. Foot compartments ambient lighting
   e. The shift stick ambient lighting
2. Was the intensity of the ambient lighting adequate?
   a. Were you able to distinguish the different lighting colours?
   b. Were the transitions in colour clearly visible?
   c. Was the flickering of the lower led lighting visible? Did it attract your attention?
3. Does the timing of the animation feel adequate compared to a realistic driving scenario? (not too short, but not too long for the evaluation)

Appendix 4 : MVP 2 User Guide

Scenario set-up Task 1: Modifying lighting pulsation frequency

In this first task you are asked to test different pulsation frequencies for the ambient lighting and dashboard LED strip, following the instructions below:

1. Open the Unity editor and in the project folder go to the scenes folder (*Assets > Scenes*) and open **scene UC1.**

2. In the **hierarchy view**, click on the component named **Timeline_UC1**, when it is selected open the timeline view on the bottom.
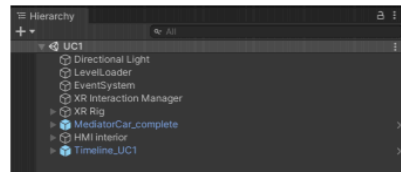
3. In the Timeline, find and select the desired animation clips (Ambient_pulsate and Dashboard_pulsate) and click the one you wish to modify.
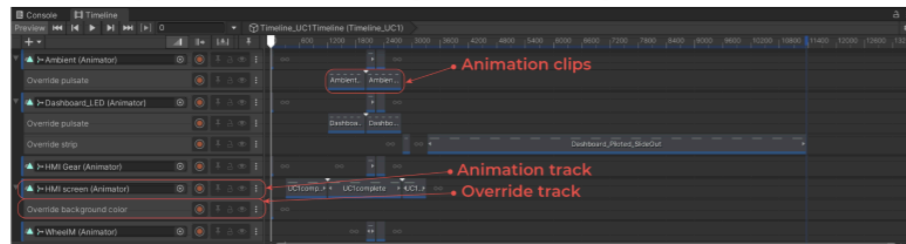
4. In the inspector window, you will see several variables that can modify the animation within the timeline. In order to change the speed/frequency of the pulsation the variable **"speed multiplier"** can be changed.
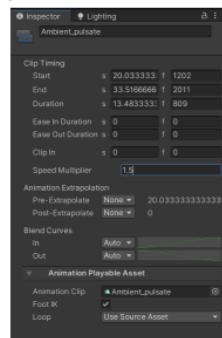
5. In order to modify the position or duration of the animation in the timeline, by dragging the clip in the desired location and clicking the end to readjust the length.

6. Repeat steps 4-5 for all of the animation clips you wish to adjust.

Scenario set-up Task 2: Modifying Background Color of instrument panel screen

In the second task, you are asked to add animation clips to the timeline as per the instructions below.

1. With the timeline window open, click on Timeline_UC1 in the inspector view. (skip this step if timeline is still open)

2. In the timeline window, find **the animation track linked to the HMI instrument panel screen**, as well as the **track override that manages the color of the screen background**.

3. To add a different color background to the screen, you must find the predefined animations. In the **project folder** go to: *Assets > Mediator_Car and HMI > HMI > HMI Animations > Screen > Background color.*
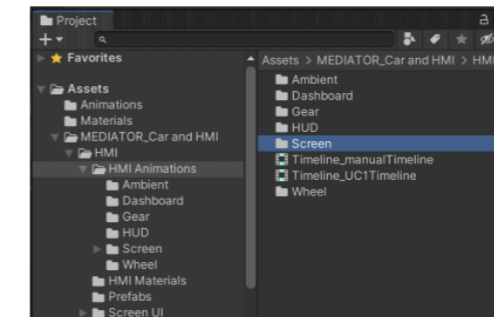
4. Drag the desired animation(s) into the "Override background color" track and position them in the desired time. You can adjust the length of an animation by pressing shift on the keyboard and dragging the end of the animation clip.

Appendix 5 : MVP 2 Evaluation Materials

Unity editor overview
The Unity editor contains several windows and tools to construct a project:
Scene view: this window shows the content of the 3D scene that is constructed. Assets/3D models can be added and previewed in the scene:

Hierarchy window: All of the assets and other components present in the scene can be viewed and selected in the hierarchy window.

Inspector view: In the inspector there are all the tools we can use to modify aspects of the various elements in the scene. By clicking on one element in the hierarchy window or timeline window, the relevant tools attached to it will become visible in the inspector.

Project folder: All of the assets and components installed with the opened project are accessible in the project folder. Assets can be dragged directly onto the scene or in other appropriate windows.

Timeline window: The timeline editor shows a constructed timeline. Animation clips can be added and arranged in this editor window.

Evaluation MVP 2 | HMI Instrument panel + ambience
Scenario: UC1 - Forced takeover

Evaluation Set-up:
Participant 1 (Mediator designer/researcher)
    Activities (2h):   - Setting up VR scenario in Unity 3D
                        - Conducting experiment with participant 2 + collecting data
    Materials: - Instructions for VR tool
    Goal: - Evaluating the use the VR tool by designers

Participant 2 (test participant)
    Activities (1h):   - Experiencing HMI through VR
    Goal: - Evaluating the experience with VR (presence)
                    - Evaluating the performance of the VR tool
                    - Evaluating the experience with the HMI

In the following pages, questions marked with P1 refer to those posed to Participant 1, the mediator designer. Questions marked with P2 were aswered bu the test participant.

P1 Questionnaire:

1. Did you perceive the Unity editor to be intuitive and easy to use?
    a. Why or why not?

2. Were you able to perform the required tasks?
    a. Did you encounter any issues when doing so?

    b. What were the issues related to?

3. Do you believe you could easily learn to use the Unity editor to apply changes to a scenario using pre-existing animations?

4. Did the provided instruction help you in performing the tasks?

5. Were the instructions sufficient and would you have been able to perform the tasks with no additional help?

1. What other modifications would you like to apply to the timeline when constructing a custom evaluation scene?

2. Would you like to have control over the single animation clips?

3. Would you like to be able to construct animation clips instead of using predefined ones?

P2 HMI evaluation Questions:

Please rate your experience with the Mediator HMI.

1. During the experienced scenario, how clear was the information given to you through the instrument panel/screen?

1. The information was not clear at all				5. The information was always clear.

2. During the experienced scenario, how clear was the information given to you through the **ambient lighting**?

1. The information was not clear at all				5. The information was always clear.

3. During the experienced scenario, how clear was the information given to you through the **dashboard LED strip**?

1. The information was not clear at all				5. The information was always clear.

4. During the experienced scenario, how clear was the information given to you through **the gear lever**?

1. The information was not clear at all				5. The information was always clear.

5. During the experienced scenario, how clear was the information given to you through **the holistic HMI** (all of the HMI components together)?

1. The information was not clear at all				5. The information was always clear.

6. During the experienced scenario, were you ever confused about **the current driving mode**?

1. I never understood what the current driving mode was.				5. I always understood what the current driving mode was.

a. Through which HMI component(s) was the **driving mode** communicated to you?

7. During the experienced scenario, were you always aware of **the time left in the current driving mode**?

1. I was never aware of the time budget left before a switch to the next driving mode.				5. I was always aware of the time budget left before a switch to the next driving mode.

a. Through which HMI component(s) was the **time left in the current driving mode** communicated to you?

8. During the experienced scenario, did you understand how much control you had over the vehicle and were you aware of the actions (driving related tasks) you were expected to perform?

1. I did not know if I had control over the vehicle and what action I was expected to perform.				5. I was always aware of how much control I had over the vehicle and what actions I was expected to perform.

Questions related to the information on the instrument panel screen:

9. When given the first alert on the instrument panel screen, did you understand that the system initiated a take over request?

10. Did you understand the reason for the system's take over request?

11. When the system initiated the takeover request, did you understand the information that was related to you?

a. Was it clear what driving mode the system would switch to?

b. Were the icons present on the screen able to convey information related to the current and next driving modes?

c. Was it clear that you could manually confirm the takeover request and how you could do so?

12. After confirming the takeover, was it clear to you that the takeover had not yet happened and a small time frame remained in which you were expected to maintain control of the vehicle?

a. Was the information about the time budget left until the take over clearly conveyed?

13. After the takeover was completed, was it clear to you that you no longer had control over the vehicle and could let go of the steering wheel?

Questions related to the information given by LED strip, ambient lighting:

14. Did the information related by the LED strip and ambient lighting in the vehicle support your understanding of the current driving mode and imminent transfer of control?

a. Did the lighting animations (pulsating) attract your attention towards the information given on the screen?

b. Did the lighting animations inspire a sense of urgency to act during the transfer of control request?

c. Did the lighting animations clearly communicate when a transfer of control was happening and/or when a transfer to a different driving mode was completed?

Additional open questions:

15. In your opinion, how could the information related by the HMI be improved?

16. Is there any additional information that you would have liked to be given by the HMI during the experienced scenario?

VR related evaluation (P2):

SUS Questionnaire:

1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

2. To what extent were there times during the experience when the virtual environment (the interior of the vehicle) was the reality for you?

1: At no time - 7: Almost all of the time

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

3. When you think back to the experience, do you think of the interior of the vehicle more as images that you saw or more as somewhere that you visited?

1: The vehicle felt like images that I saw - 7: The vehicle felt like a place that I visited

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

4. During the time of the experience, which was the strongest on the whole, your sense of being in the vehicle or of being elsewhere?

1: I felt like being somewhere else - 7: I felt like being in the vehicle

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.
My memory of the interior of the vehicle is similar to that of other places I have visited today:

1: Not at all - 7: It is very similar

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

6. During the time of your experience, did you often think to yourself that you were actually in the vehicle?

1: Not at all - 7: Very often

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| O | O | O | O | O | O | O |

Additional open questions:

7. In your opinion, what could have improved your feeling of being in the interior of the vehicle?

8. Which elements in the environment/events experienced have made feel like you were not actually in the vehicle?

Appendix 6 : MVP 3 Evaluation Materials

SUS Questionnaire:

1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.

1	2	3	4	5	6	7
O	O	O	O	O	O	O

2. To what extent were there times during the experience when the virtual environment (the interior of the vehicle) was the reality for you?

1: At no time - 7: Almost all of the time

1	2	3	4	5	6	7
O	O	O	O	O	O	O

3. When you think back to the experience, do you think of the interior of the vehicle more as images that you saw or more as somewhere that you visited?

1: The vehicle felt like images that I saw - 7: The vehicle felt like a place that I visited

1	2	3	4	5	6	7
O	O	O	O	O	O	O

4. During the time of the experience, which was the strongest on the whole, your sense of being in the vehicle or of being elsewhere?

1: I felt like being somewhere else - 7: I felt like being in the vehicle

1	2	3	4	5	6	7
O	O	O	O	O	O	O

5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.
My memory of the interior of the vehicle is similar to that of other places I have visited today:

1: Not at all - 7: It is very similar

1	2	3	4	5	6	7
O	O	O	O	O	O	O

6. During the time of your experience, did you often think to yourself that you were actually in the vehicle?

1: Not at all - 7: Very often

1	2	3	4	5	6	7
O	O	O	O	O	O	O

Additional open questions:

7. In your opinion, what could have improved your feeling of being in the interior of the vehicle?

8. Which elements in the environment/events experienced have made you feel like you were not actually in the vehicle?

9. Did you experience the interaction with the virtual objects as being natural? If not, what made the experience unnatural?

Appendix 7 : User Manual

The manual is designed to help users in navigating the Unity project of the Mediator VR tool.

The content of the User Manual is included entirely in the following pages.

Mediator VR Evaluation Tool

User Manual

A step-by-step guide custom evaluation scenes using Unity Game Engine

Author:
Anna Aldea

Index

Glossary

In this User Manual the terms defined below, which are specific to the Unity Game Engine, will be used.

- **GameObject / Object:** Any object found in a Scene, which can represent characters, props, scenery, cameras, waypoints, and more. A GameObject's functionality is defined by the Components attached to it.
  https://docs.unity3d.com/Manual/GameObjects.html

- **Asset:** Any media or data that can be used in the project. Assets are stored in the Project folder.

- **Prefab:** An asset type which acts as a container of a GameObject, complete with components and properties.
  https://docs.unity3d.com/Manual/Prefabs.html

- **Scene:** Assets which contain all of the environments and elements of an application. Each scene represents a unique "level". Application can be simple, containing a single scene, or be more complex, with multiple scenes or "levels".
  https://docs.unity3d.com/Manual/CreatingScenes.html

- **Build / Building:** The process of compiling your project into a format that is ready to run on a specific platform or platforms.
  https://docs.unity3d.com/Manual/BuildSettings.html

For more information on terms in the Unity editor, you can consult the following link: https://docs.unity3d.com/Manual/Glossary.html#SectionCore

Introducing The Mediator VR Evaluation Tool

The **Mediator VR Evaluation Too**l has been developed using the **Unity 3D Game Engine**.

GENERAL INFORMATION

- The tool was created using Unity version **2020.6.6f1.**

- The **XR Interaction Toolkit package** is used in this project. It is an interaction system which provides a framework for various VR interaction tasks and cross-platform support. (https://docs.unity3d.com/Packages/com. unity.xr.interaction.toolkit@1.0/manual/index.html)

- This project was built for and test on both **HTC Vive** and **Oculus Quest** platforms.

In order to set-up custom experiments using the tool, you will need to learn how to navigate the Unity Interface and use the various assets and scripts included in the project.

This User Manual will guide you step-by-step in creating and building your own evaluation scene (see Section 2). But first, we will introduce the main elements of the VR Evaluation Tool.

Unity 3D Interface

An overview of Unity's interfaces and the various windows and tools used for this project.

Prefabs

A list of prefabs created for the Mediator VR Evaluation Tool, explaining how they are made and how they sould be used.

Unity Timeline

An overview of the Unity Timeline and its functionality. Essential to understanding how to create your own custom scenarios.

Unity 3D Interface

When opening the main editor window of Unity, you will notice that the interface of Unity 3D is made up of small windows, as shown in the image below.

Note that the windows can be rearranged or grouped in one position. To view hidden windows you must click on their name at the top of the window, as shown in the image with the Animation window.

Layout of the Unity, as arranged for the Mediator VR tool.

More information on the Timeline editor is found on page 20.

Scene View

Animation window

Hierarchy Window

Inspector Window

Timeline Editor
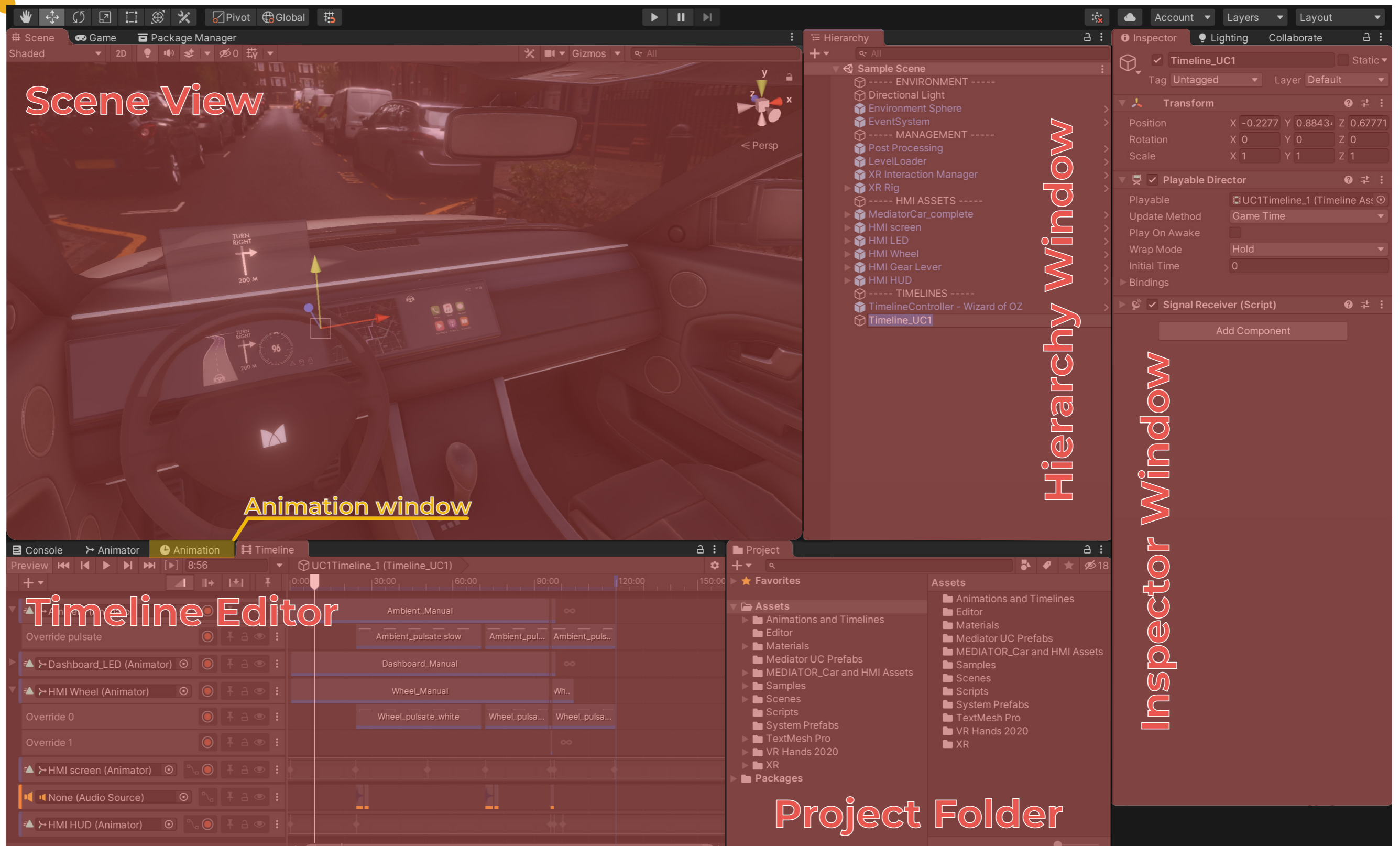
Project Folder

Project Folder

In the project folder we finds the library of assets and packages which are used in the project. These include all scenes, scripts, prefab objects, animations, images, audio files and other additional files that are implemented in the project.
Everything that needs to be accessed in the project file can be found here.
https://docs.unity3d.com/Manual/ProjectView.html

Scene View

The Scene View allows us to view and navigate the tridimensional scene that we have created. When a visual element is added to scene, it will become visible and can be moved and rotated in the desired position.
https://docs.unity3d.com/Manual/UsingTheSceneView.html

Hierarchy Window

The Hierarchy Window contains all object available in the scene, grouped in a hierarchical representation.
In the Hierarchy, we find the Scene, as "parent object" containing everything else.
https://docs.unity3d.com/Manual/Hierarchy.html

Inspector Window

The Inspector allows us to inspect and analyse all the editable properties of an object, that is selected in the Hierarchy. Different objects have specific sets of properties (e.g. a transform component, colliders, mesh renderes, scripts and many more) When an object in the Hierarchy or project folder is selected, the inspector window will show all the available information about it, with the properties available for editing.
https://docs.unity3d.com/Manual/UsingTheInspector.html
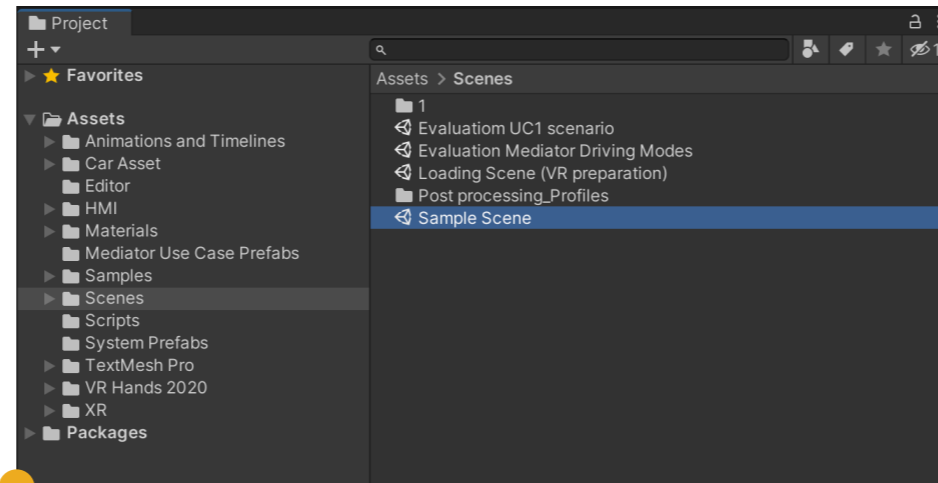
Scenes Folder in the Project window.
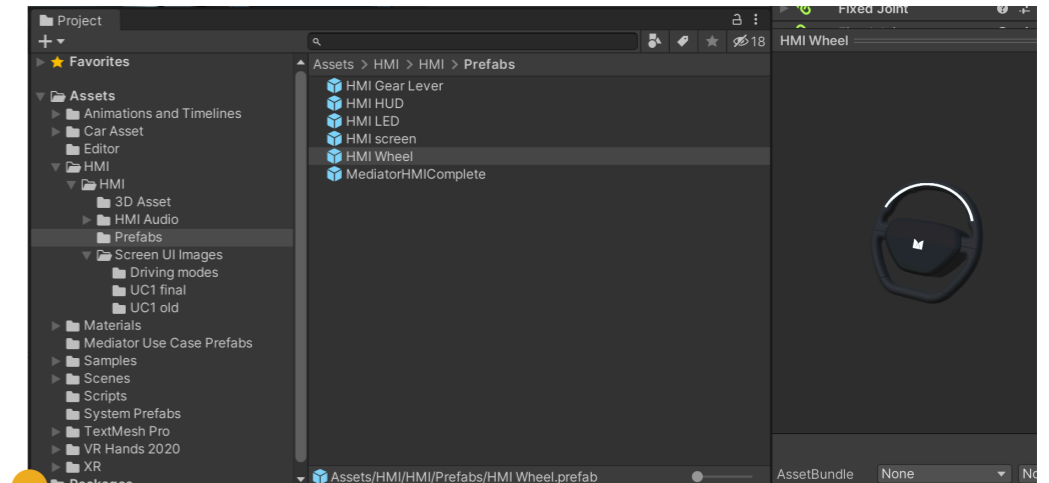
Mediator HMI prefab assets in the Project window.
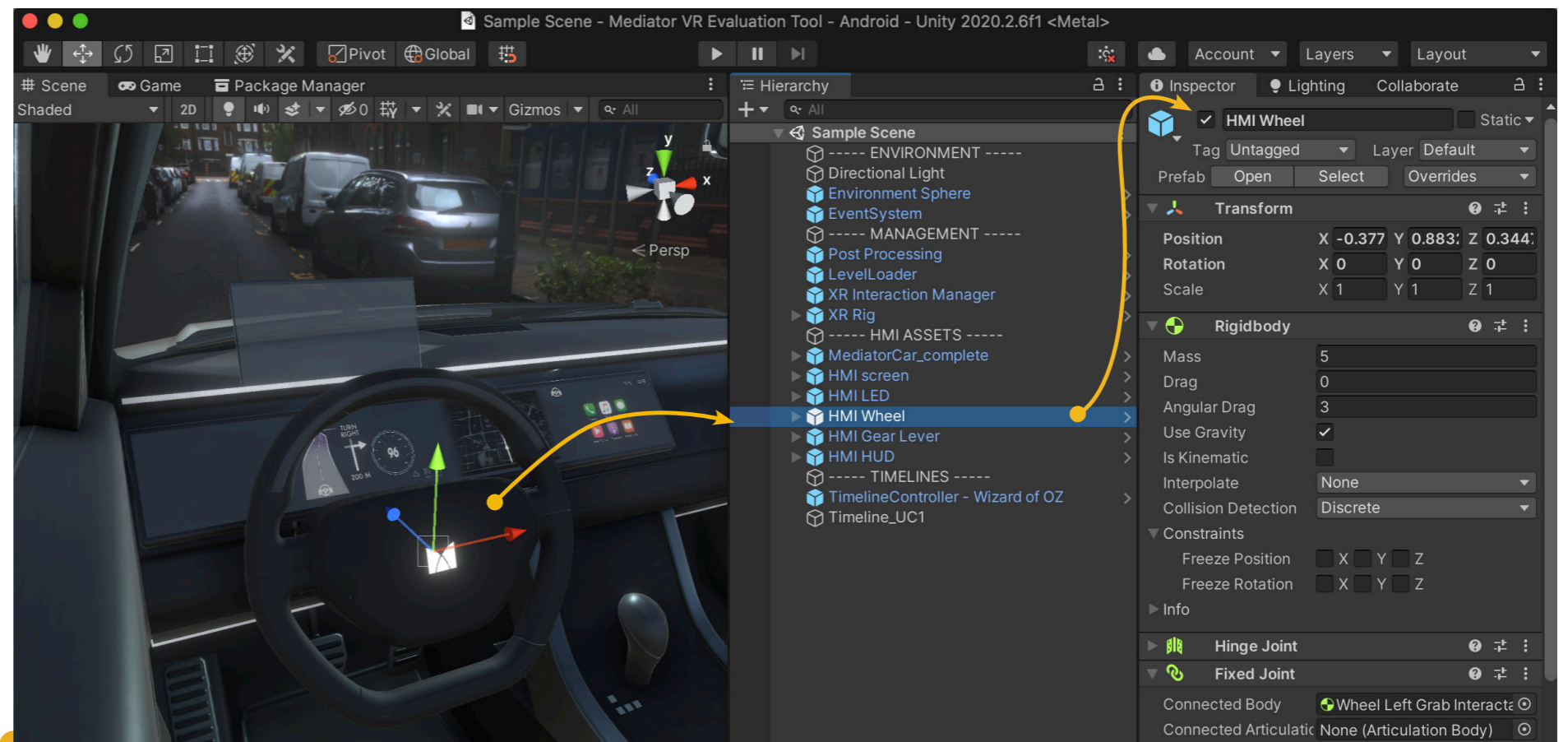
Information displayed for a selected object in the Scene, Hierarchy and Inspector windows.

The image above shows the **relationship between the Scene, Hierarchy and Inspector**. The selected object, The "HMI Wheel", is shown with a translation gizmo (arrows) in the Scene View, indicating that is can be moved. In the Inspector windows, the editable properties of the object are now visible. Variables that are modified in the Inspector window will be visible in the Scene view. For example changing the value related to the position of the object in the "transform" component, will move the object to a new location in the scene.

Prefabs

In order to simplify the task of creating custom scenes for the evaluation of the Mediator HMI designs, a number of prefabs were created, which are ready to be added to the scenes and used.

Prefab assets are a special type of component that allows fully configured GameObjects to be saved in the Project for reuse. These assets can then be shared between scenes, or even other projects without having to be configured again.

For more information on the Unity prefabs system you can access the Unity Manual: https://docs.unity3d.com/Manual/Prefabs.html

In the following section, we will give an overview of the main prefabs created for the Mediator HMI and their characteristics.
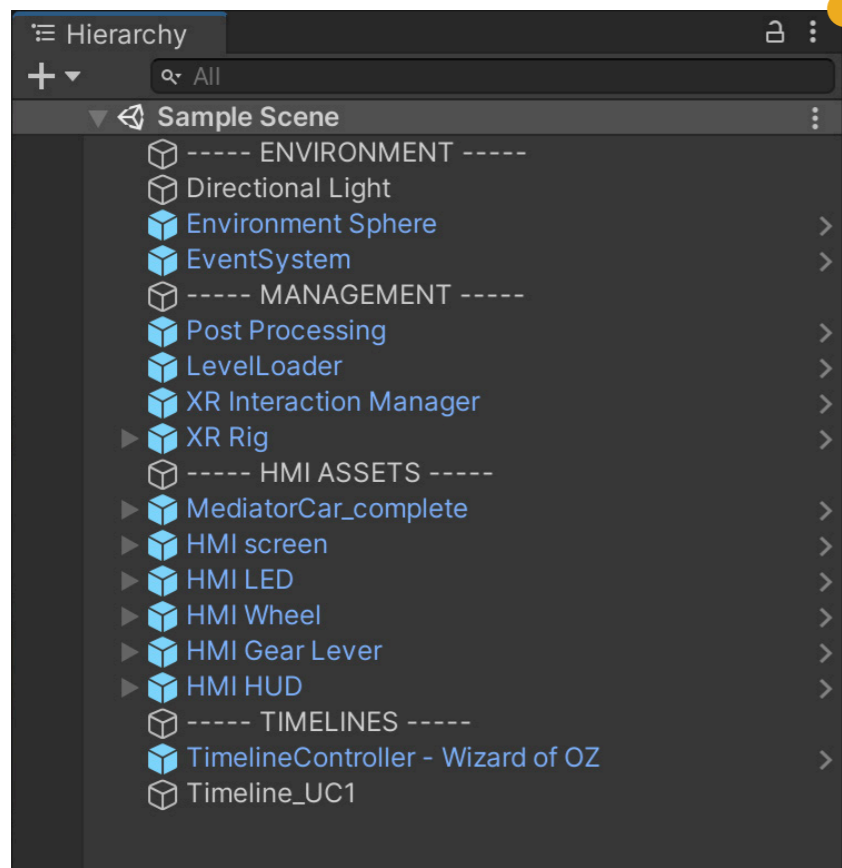
When added to the Hierarchy window, prefab objects are displayed in blue.

System Prefabs

The project contains a number of prefabs that are essential to the working of the VR application and to the management of the scenes. The majority of these components do not contain any visual elements, but must be added to the Hierarchy to insure that the application will run smoothly.

The following lists detail the necessary and optional system prefabs:

Necessary:

XR Rig: This component allows the player to see, move and interact with the virtual scene. It contains the Main camera, which moves with the player's head, and hand avatars which follow the movement and input of the VR controller.

XR Interaction Manager: This component manages the interactions perform in VR and is related to the XR Interaction Toolkit, used in the project.

Level Loader: This component contains a custom script, which allows researchers to remotely load new scenes during the evaluation through the use of a remote keyboard.

Post Processing: This component defines the post processing effects rendered on the Scene.

Optional:

Environment Sphere: This prefab is an inverted share onto which 360° images of road environments are displayed, to recreate the feeling of being on the road. This component can be added when displaying an exterior environment is desired for the experiment that will be conducted.

Timeline Controller - Wizard of OZ: This component contains a custom script which allows users to play or pause timelines in the scene remotely during the evaluation moment, by attaching a list of keyboard keys to the list of timelines in the scene.

Timeline Control - Master Timeline: This component shows an example of how a master timeline asset can be set up to combine different timelines in a scenario or simply display them in the desired order. This prefab can de added to the scene, packed and modified or referenced as an example for creating a custom master timeline.

More information about these prefabs is given in section two of this User Manual and in the related video tutorials.

HMI Prefabs

The Mediator VR Evaluation Tool Unity project includes five Prefab Objects related to the varios Mediato HMI components.
Each of this objects is constructed to recreate the look and behavior they would exhibit in real life. The objects are animated and have a variety of existing animation clips, which are combined to simulate different behaviours.

The HMI Wheel and HMI Gear Lever prefabs both contain interactable components (part of the XR Interaction Toolkit), which allow users to interact with the objects in VR, by grabing and moving them with their hands.

HMI Screen

"Centre"   "GPS"   "Media"
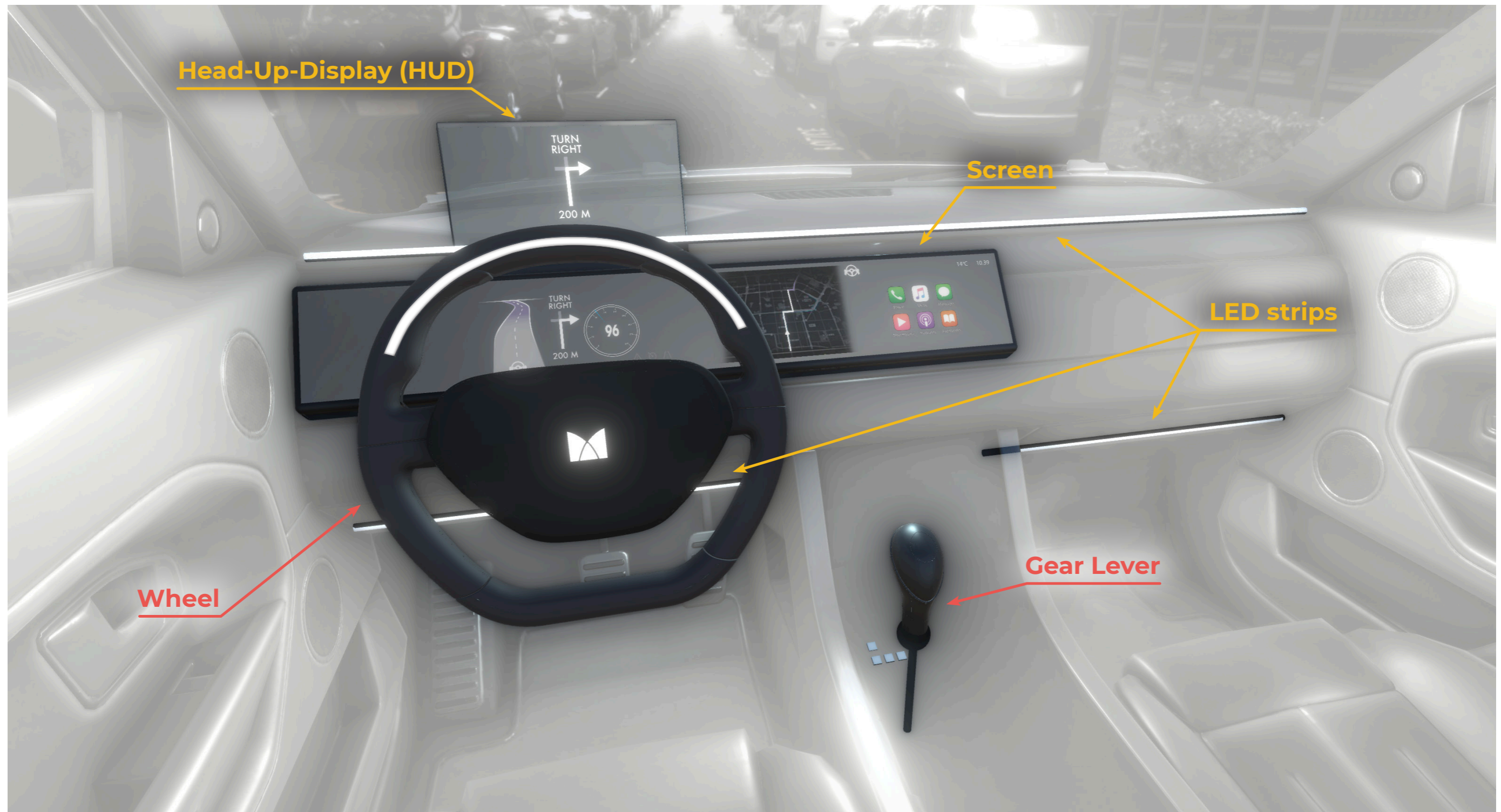
The **HMI screen prefab** is built using Unity's UI elements. A UI Canvas component, the ***HMI_instrumentCanvas***, holds three different images which represent various parts of the screen: the instrument panel, called ***Centre***; the ***GPS***; the ***Media*** display.

Each of these components is animated to display different frames, representing the changes in the Mediator screen's UI in different use cases.

In the Hierarchy the Centre component, which is a child of the HMI_instrumentCanvas, is selected. In the inspector, we can see the image which is currently applied to the component.

The HMI_instrumentCanvas, holds three image components: Centre, GPS and Media.
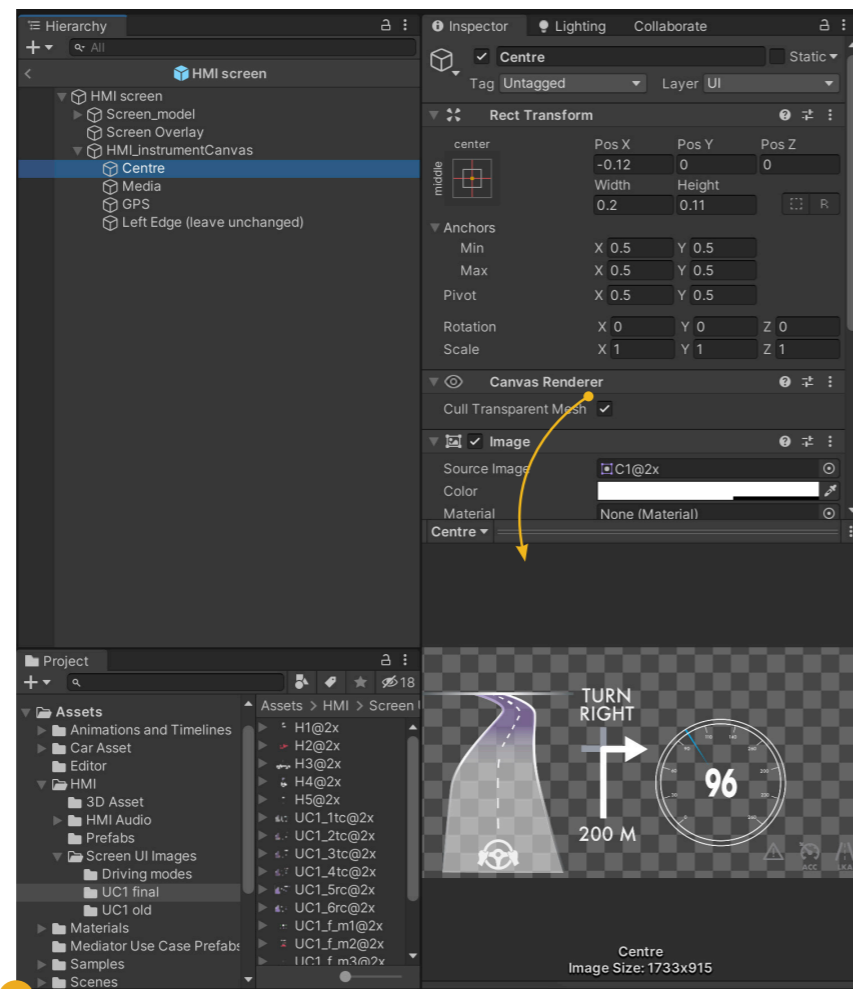
HMI HUD (Head-Up-Display)

The HUD component has a canvas and a single Image component.

The **HMI Head-Up-Display prefab** is built in the same way as the HMI screen prefab, shown on the previous page. In this case, the UI Canvas, ***HMI_HUDCanvas***, only has one image component, ***Image***.

Note: The *HMI_HUDCanvas* and *HMI_instrumentCanvas* are both set to be rendered in World Space. As such, **they must have an Event Camera attached.** This will be the camera though which we can view the images in the canvas. As shown in the image on the left, **our main camera is a child of the XR Rig**.
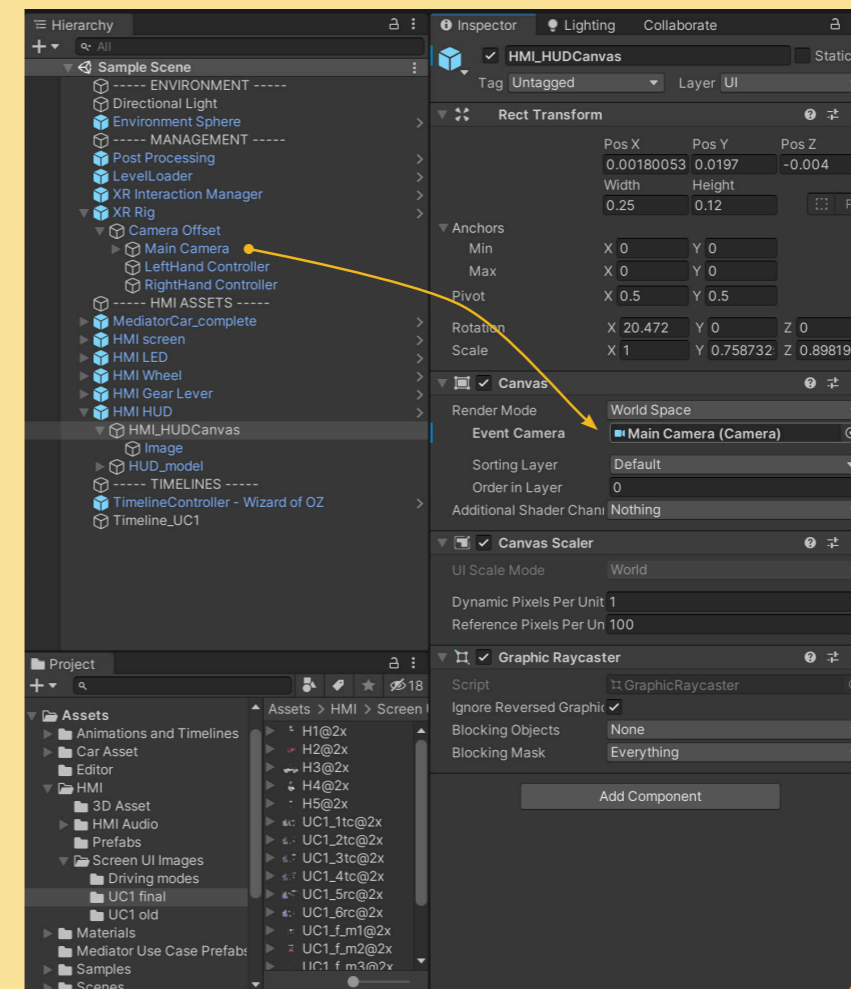
If you are not able to view the UI elements in your scene, check that the two canvas components; Event Camera is set up correctly.

The image shows the relationship between the Event Camera variable of the Canvas component, HMI_HUDCanvas, shown in the Inspector and the Main Camera object, which is a child of the XR Rig, seen in the Hierarchy view.

HMI LED

The **HMI LED prefab** is a simple object, containing a low number of elements: the *Dashboard LED* strip and two LED strips placed underneath the foot compartment, which create *Ambient* lighting.

These two child objects are animated to recreate the behaviour of the Mediator lighting design. Because they can exhibit small differences in the way the behave, for example, the Dashboard LED can decrease and increase in length to represent time budget, they are animated separately. Each child has its own **Animator component**, as shown in the images below.
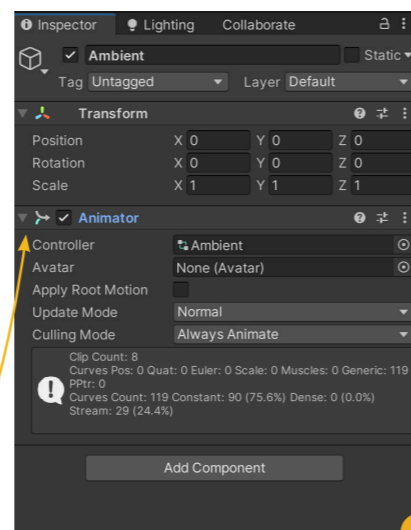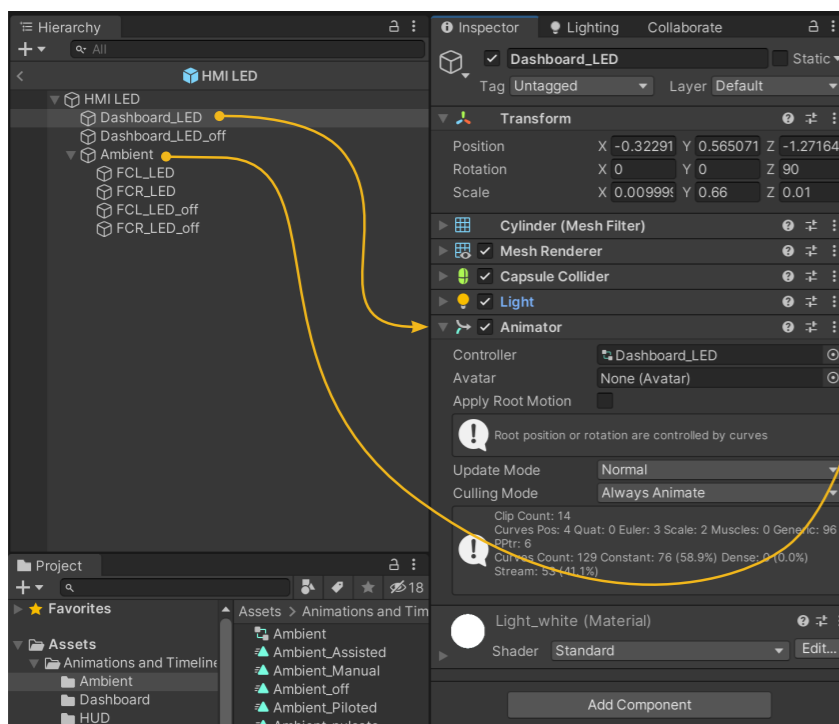
Compared to other HMI prefabs, the HMI LED prefab has two child objects which are animated separately.

HMI Wheel
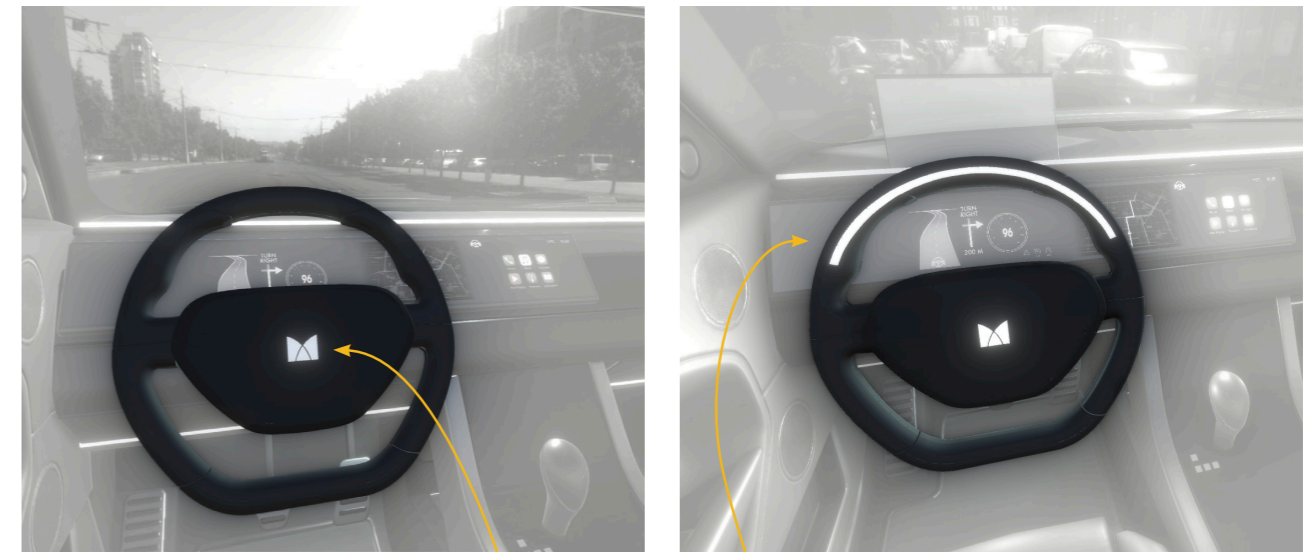
The **HMI Wheel prefab** contains two children objects that are part of the lighting design of the Mediator HMI: *the Mediator logo and the wheel LED strip*. These are part of the wheel object, rather than the HMI LED prefab, as they must follow the movement of the wheel.

If one of these elements is not necessary in the scene, **they can be deactivated from the Inspector window** as shown in the image on the right.

The **HMI Wheel prefab is an object that users can interact with**, grabbing (by pressing a button on each VR controller, as explained in section 2.5) and rotating it. This interaction is made possible though four *Grab Intractable* components, that **are part of the XR Interaction Toolkit.**
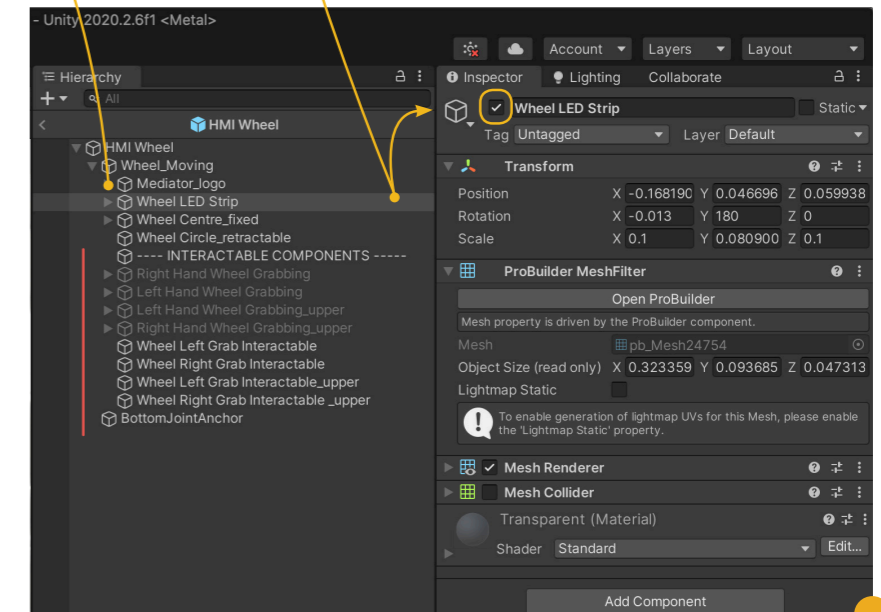
The HMI Wheel has several children objects, as seen in the Hierarchy view. The Mediator _logo and Wheel LED Strip components can be activated or deactivated by ticking the box highlighted in the Inspector window.

The components which define the physical intraction with the wheel, highlighted in orange, should not be modified.

HMI Gear Lever

The gear lever can snap into four different positions. Using the Socket Interactor events, moving the gear into one of the positions can become a trigger for an action, such as playing a Timeline asset.
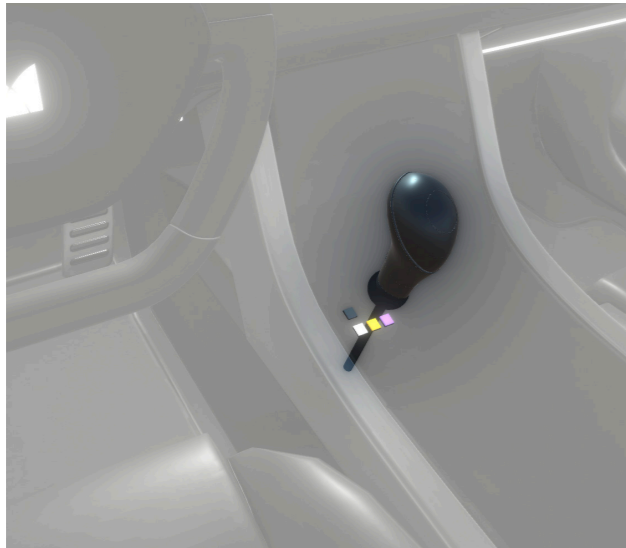
The **HMI Gear Lever prefab** is an intractable object. Similarly to the HMI Wheel, it can be grabbed and moved through a Grab Interactable component. This object allows extra functionality, as it can be set up to automatically play Timeline assets when the user moves the gear into one of the four positions.

The four positions (NeutraL, Manual, Assisted and Piloted) are defined by four **Socket Interactable components**, also part of the XR Interaction Toolkit. **These are invisible objects which allow an object, in this case the gear, to snap into a predefined position.** This interaction will activate a number of events, which can be seen in the Inspector window under the XR Socket Interactor's **Interactor Events lists**. The Select event, is activated when the gear lever is snapped into the specific Socket.

In order to automatically play a Timeline through the interaction with the gear lever, an event can be added to the Select list, as shown in the previous image.

To set up the event we can **drag in the object we wish to control from the Hierarchy** view. Then, we can **select one of the existing functions available** for the object. In the image below we can see how to set up the Play() function of on object with a Playable Director component.
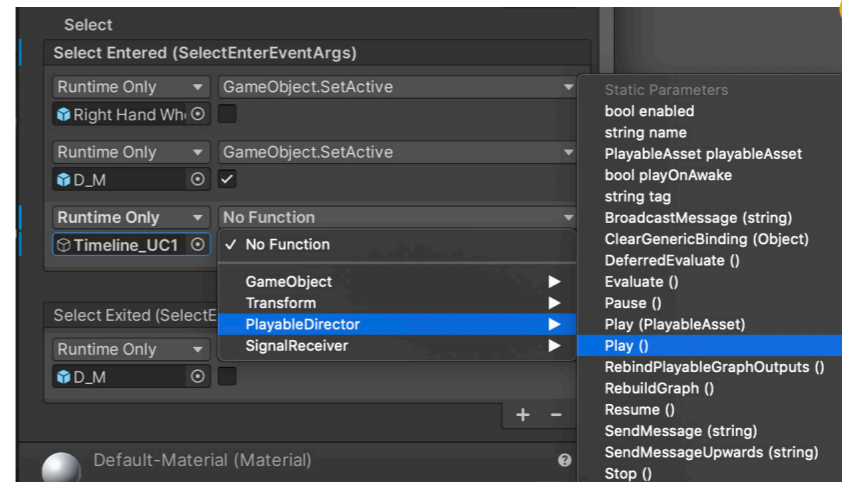
An example for how to play a Timeline asset using the Socket Interactor events.

Several functions can be set to execute when the interaction with the Gear is performed.

GEAR STARTING POSITION

The Gear Lever prefab has a custom script attached to it called ***Gear Lever Positioner***, see image below. This scrips **allows us to define the position in which the gear will be at the start of our Scene.**

For example, if our evaluation scenario starts with the vehicle driving in assisted more, we can tick the Gear in Assisted variable. When the scene starts, the gear lever will be in the correct position.
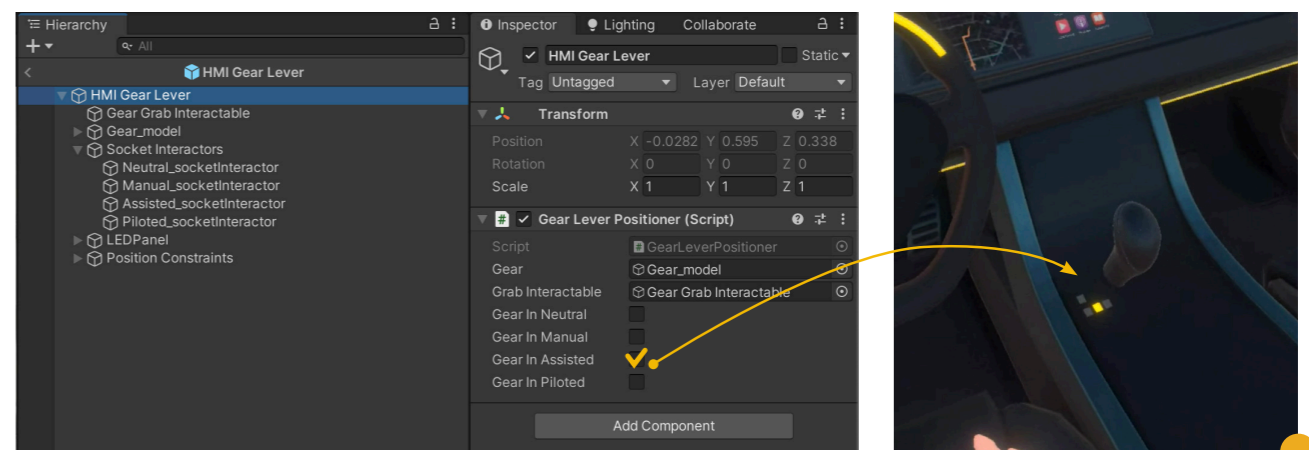
Set up the starting position of the HMI Gear Lever object by ticking ne of the variables.
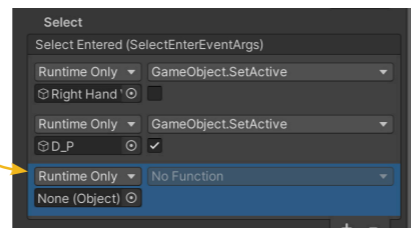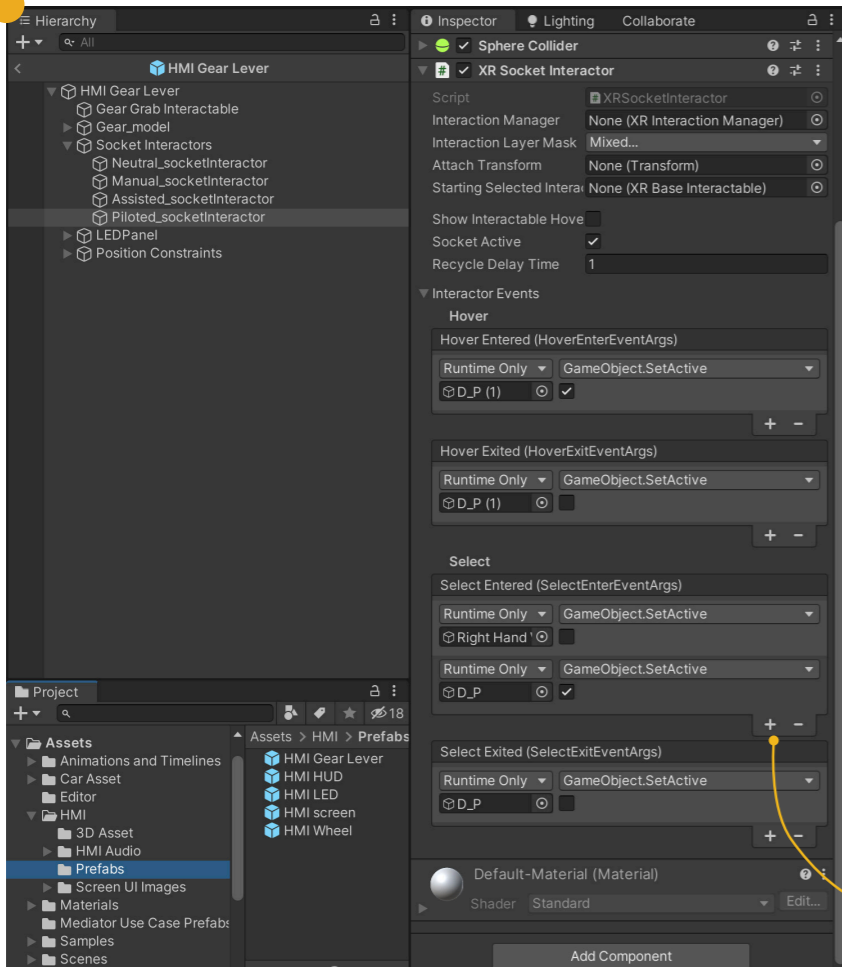
Unity Timeline

Unity Timeline (https://docs.unity3d.com/Packages/com.unity.timeline@1.2/manual/tl_about.html) is a tool that allows us to create complex scenarios by managing the objects in the scene. **With the timeline, we have the ability to control animations and position them in time, but also to activate/deactivate objects and perform specific events on the time axis.**
The Timeline is an important piece of the Mediator VR Evaluation Tool, as it is used to synchronise animations associated with different Mediator driving modes and Use Case scenarios, recreating the HMI behaviour in each of these situations.
In order to create custom scenes for an evaluation of the HMI, it is important to have a basic understanding of the Timeline and each of its tracks.

Similarly to video editing software, in the Timeline editor window we can add various components called tracks. **Different types of tracks can be used for different purposes:**

TIMELINE TRACKS

- **Animation tracks:** Use Animation tracks to add Animation clips that animate a bound object in the scene.
- **Activation tracks:** Use Activation tracks to add Activation clips which set when the bound object is active (shown). The object is bound to the Activation track.
- **Audio tracks:** Use Audio tracks to add Audio clips for playing background music or sound effects.
- **Control tracks:** Use Control tracks to add Control clips which are special clips that control different object in the scene, including other Timelines.
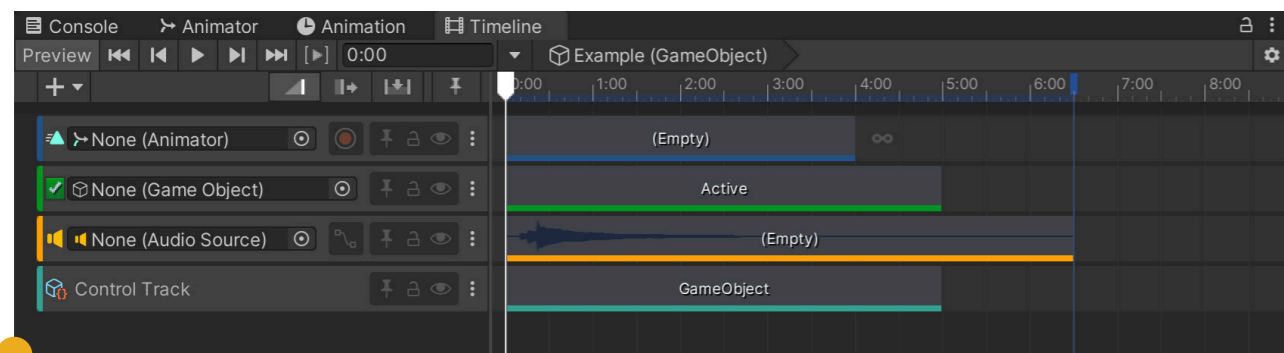
💡 *Example of Timeline tracks. From top to bottom: animation track, activation track, audio track and control track.*
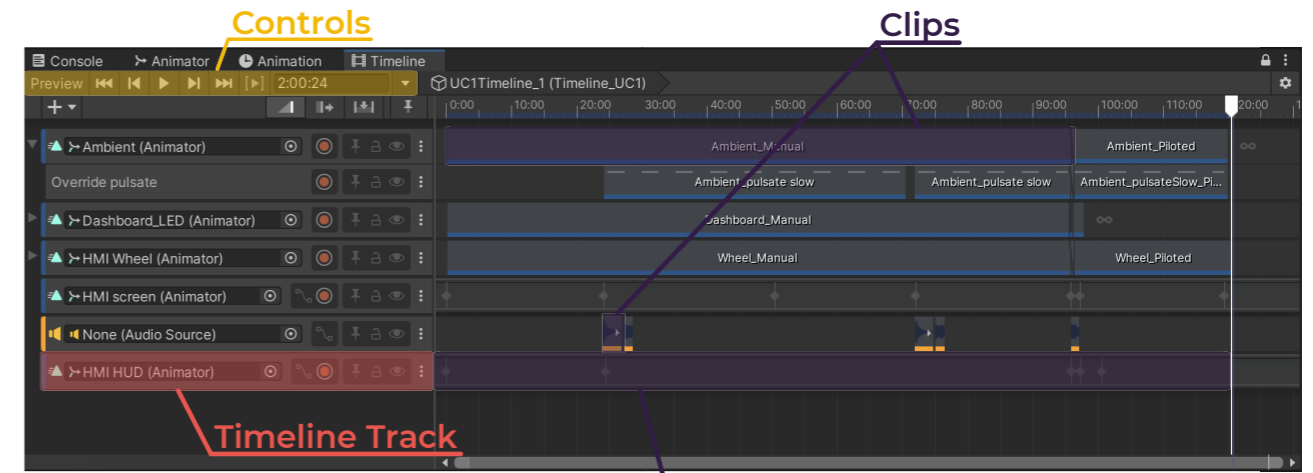
💡 *Overview of the Timeline editor window.*

NAVIGATING THE TIMELINE WINDOW

Events created with the Unity Timeline can be previewed directly in Unity's Scene view by using the **controls** on the top left corner of the Timeline editor. When the "preview" button is toggled on the timeline can be played and paused.

Timeline tracks are displayed in the track list. Each track in a timeline can contain multiple **clips** (e.g. animation clips, audio clips) and is linked to an object that exists in the scene. These links are referred to as bindings.

Note: When an existing Timeline asset is added to a Scene, it is important to recreate the **bindings between the tracks and the correct objects** (see image below). An exception to this is the audio track. While audio tracks can be linked to an audio source in the Hierarchy, these are not necessary.
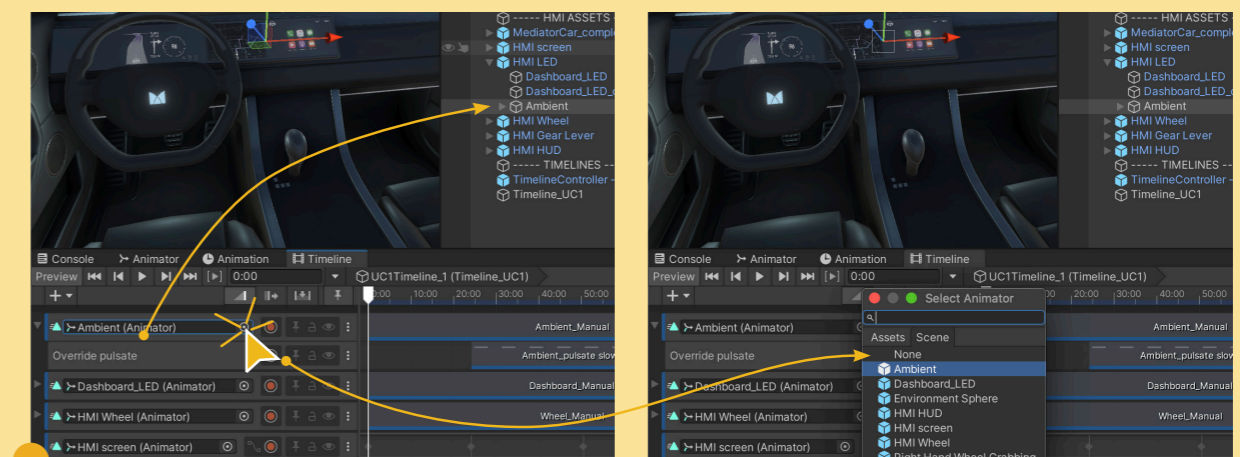
💡 *Creating bindings between tracks and objects in the scene.
On the left, we can see the relationship between the a track and an object in the hierarchy window. In order to link the track to the binding we can click the icon next to the track name and choose between the components available in the scene (right).*

Creating a Custom Scene with the Mediator VR Evaluation Tool

Follow the steps presented in this chapter to easily create a custom scene to use in your experiment for the Mediator HMI.

You will be guided through the process step-by-step, from creating a new scene, to creating a custom scenario by modifying the contents of the scene. Finally, you will be given tips for how to prepare for an evaluation using the Mediator VR Evaluation Tool.

Remember to consult the previous section of this User Manual for more information on the characteristics of the HMI prefabs and the Unity Timeline.

A number of **video tutorials** have ben crated to explain to demonstrate the actions you can or must take in some steps. **Watch these if you need more information to complete one of the steps.**

1 **Creating a New Scene**

Create a Scene that you can customize by either:
1. Duplicating the Sample Scene, containing all necessary objects.
2. Creating a new Scene and adding in all the necessary objects.

2 **Customising Scene Content**

Customize your Scene by making the desired changes to the objects. You can add or remove objects, or change their size, position and appearance.

3 **Using the Unity Timeline**

Create a scenario by including in your scene one of the existing Timeline assets. Choose one of two methods to play various Timelines throughout your expeeriment. Modify Timelines as desired.

4 **Building Evaluation Scenes**

Build the Scene or Scenes that you created. Set up the keybord controls required to start your scenes during the evaluation.

5 **Using the VR tool During the Evaluation Moment**

Follow these instructions to prepare test participants for the experience using a VR device and to control the application remotely using keyboard inputs.

1 Creating a New Scene

A Scene in Unity, is the space where you work with the content of the application. In the Scene, you must add all assets and components that are necessary, such as the environment and objects that are displayed, but also objects that contain scripts which allow the application for function as intended.

For an experiment you can create a single Scene, if you would like to show participants a single scenario, or multiple Scenes, for example, if you would like to expose participants to different HMI designs.

SCENE CONTENTS

Necessary Objects
These objects must be added to every Scene. With few exceptions, these objects and their children can remain unchanged.

Flexible Objects
These objects can be removed from the scene or modified to fit the experiment.
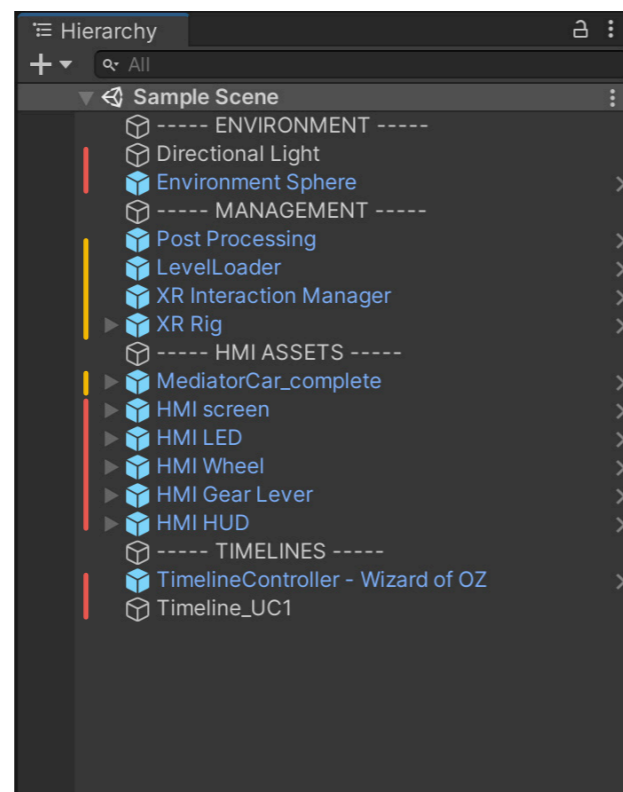
To start building your own custom Scene you have **two options**: duplicating the existing Sample Scene or creating a new Scene to which you can add the necessary components.

1. DUPLICATING THE SAMPLE SCENE

To create your custom scene you can start by duplicating the existing "Sample Scene", which can be found in the Project Folder: **Project > Assets > Scenes**

In order to duplicate a scene simply select the scene and, on your keyboard, click **Ctrl+D** (or command+D on macOS).

> ▷ Watch the following video to see how this is done: **Duplicating the Sample Scene**
>
> (https://swov2.sharepoint.com/:f:/r/MEDIATOR/ Shared%20Documents/SWOV%20intern%20 -%20onderzoek/WP1/T1.5/Time%20budget%20 concept/Anna/User%20Manual%20-%20 Mediator%20VR%20Evaluation%20tool/Video%20 Tutorials?csf=1&web=1)
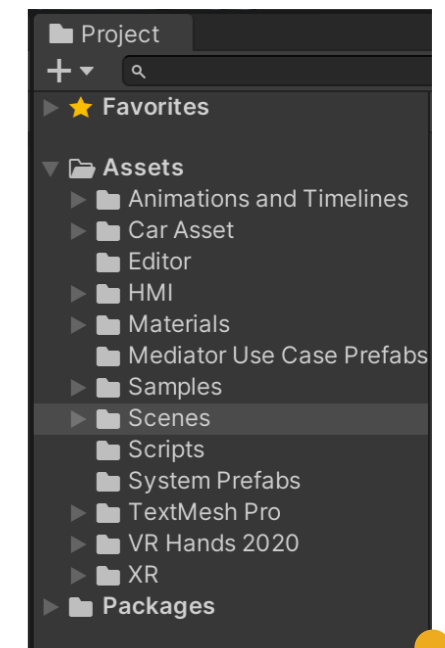
Scenes Folder in the Project Window.

2. CREATING A NEW SCENE

To create a new Scene you can go to the Scenes folder (Project > Assets > Scenes). In the folder, **right click and choose Create > Scene**.

After opening your new Scene, it is important to add all of the necessary components (see *Scene Contents*, p. 22), as well as the assets that you would like to include in you experiment.

These can be found in the Project Folder, at the following locations:

Project > Assets > System Prefabs
Project > Assets > Car Asset > Modified Car Asset > Car Prefabs
Project > Assets > HMI > Prefabs

> **Note:** When assets, such as prefabs and Timelines, are added to a scene, it is important to check that the necessary **bindings** between their components and other objects in the scene are recreated. **See the notes on pages 15 and 21** for examples of bindings that are necessary in this Unity project.
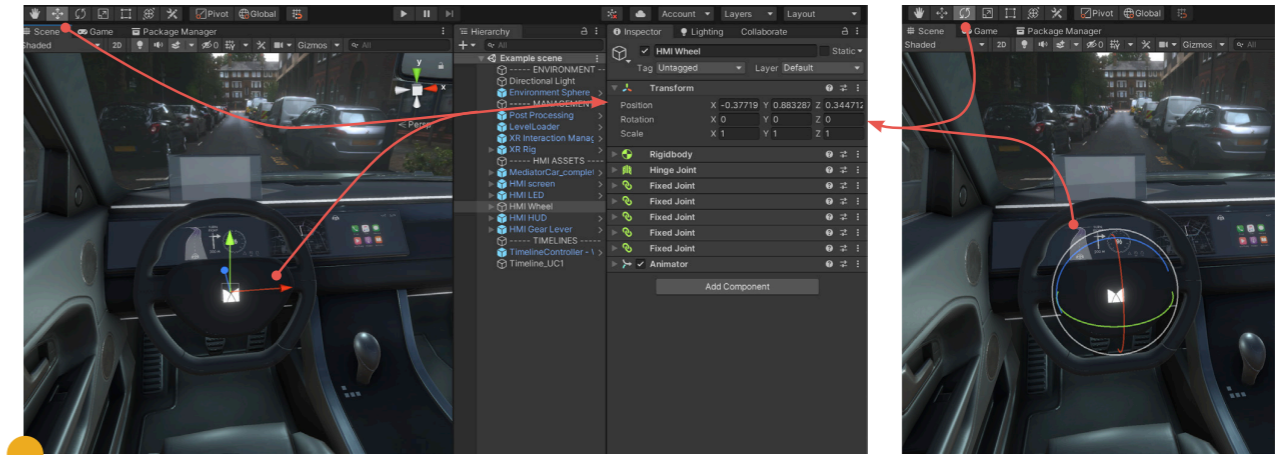
② Customising Scene Content

The Scene should contain all of the Mediator HMI components you might want to display during your evaluation. The first step in customising your Scene is deciding which HMI prefabs you would like to add or remove from your scene. All HMI component prefabs can be retrieved from (**Project > Assets > HMI > Prefabs**)

Next, you can decide to modify them to your linking.
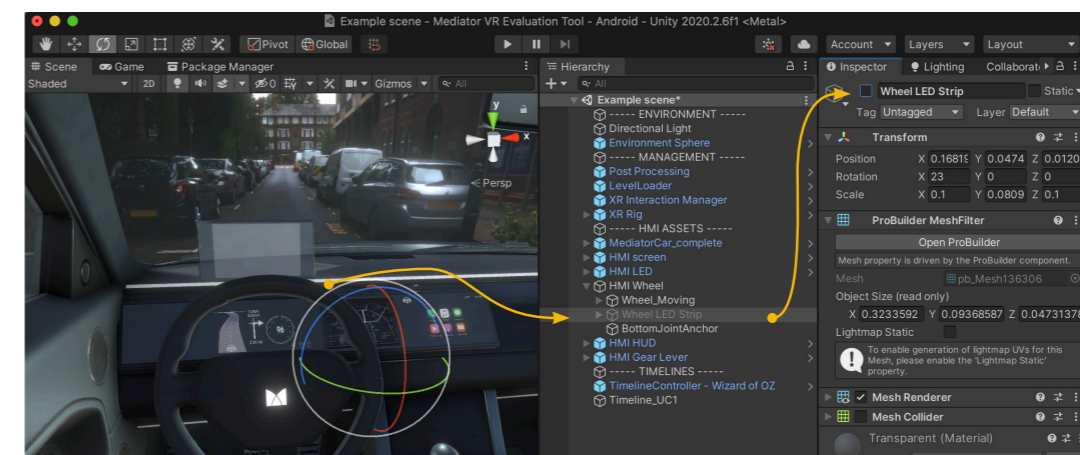
Possible customisation:
- Changing an object's position in the scene.
- Changing the size of an object.
- Activating of deactivating child components of the prefab.

Watch the following tutorial to get an overview of the ways in which you can customise your scene: **Customising Scene Content_HMI prefabs**

(https://swov2.sharepoint.com/:f:/r/MEDIATOR/Shared%20Documents/SWOV%20intern%20-%20onderzoek/WP1/T1.5/Time%20budget%20concept/Anna/User%20Manual%20-%20Mediator%20VR%20Evaluation%20tool/Video%20Tutorials?csf=1&web=1)

Note: In order to avoid the changes made to an HMI component to be saved to all of the instances of the HMI prefab across all of the project and in all scenes. **It is important to remember to first Unpack the prefab completely**, as shown in the image.

The position, rotation and scale of objects can be change in the transfrom component that is found in the inspector when selecting an object.
Using the gizmos on the screen, changes can be made directly by dragging the arrows and lines in the scene view.
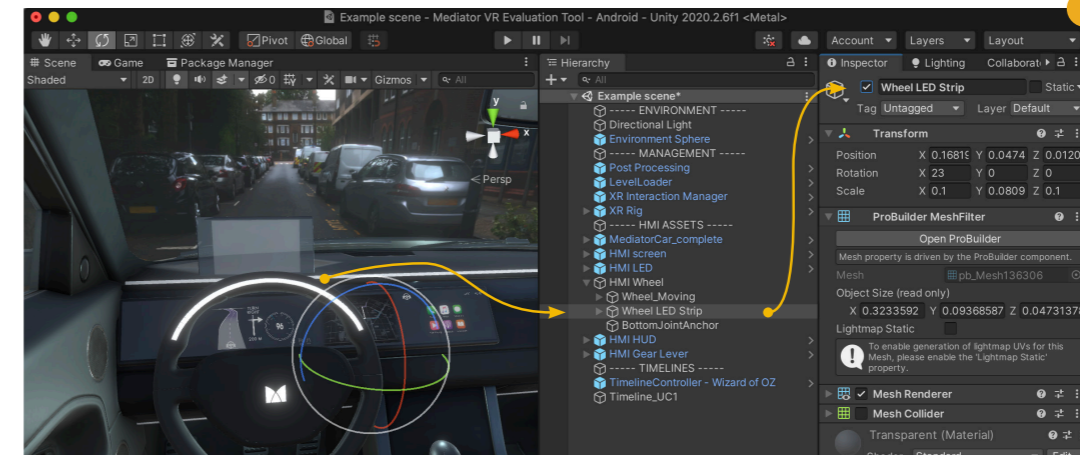
Objects, including child objects, can be activated or deactivated at the top of the inspector window. Deactivating an object will render it invisible in the scene.

③ Using the Unity Timeline

To animate the Mediator HMI components in the Scene and create various evaluation scenarios, we use the Unity Timeline. Several Timeline assets can be added to your scene and activated at different moments, to create complex scenarios within a single Scene.

Follow the instructions in the next subsections to create a custom scenario in your Scene, using the Timeline tool.

ADDING TIMELINE ASSTES TO THE SCENE
The project includes a number of **Timeline assets**, representing the HMI in various driving modes and use cases, that can be added to the scene. These existing assets can be retrieved from the Project Folder: **Project > Assets > Animations and Timelines > Timelines**

In order to add a Timeline asset to a scene, **we must first create an empty gameObject in the Hierarchy window.** This can be done by right clicking on an empty space in the Hierarchy and choosing Create Empty in the pop-up menu, as shown in the image on the right.

Next, **we need to add the Playable Director component to the empty object** from the inspector window (see image on the next page).

Finally, **we can assign a Timeline asset to the Playable variable of the Playable Director** component by selecting one, as shown on the next page, or by dragging it into the field from the Project window.
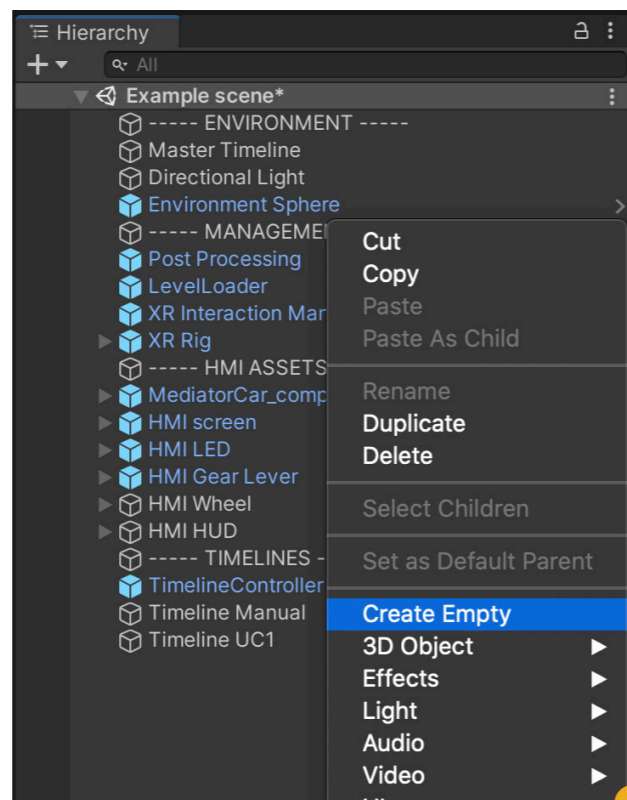
Right click in the Hierarchy window and select "Create Empty" to add a new gameObject to the scene, which can house the Timeline asset

> **Note:** After a Timeline asset is added its tracks must be linked to the animated objects in the Scene. **See the note on page 21** and follow the instructions in order to create the necessary bindings.
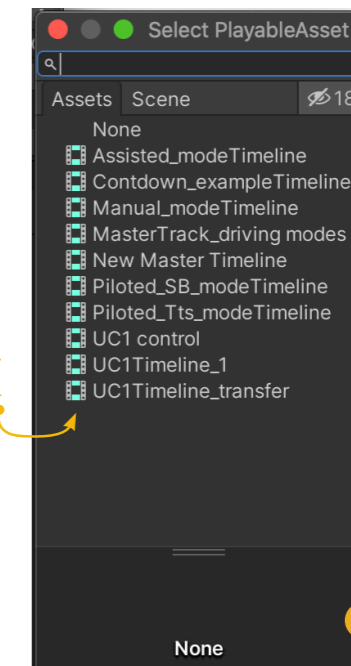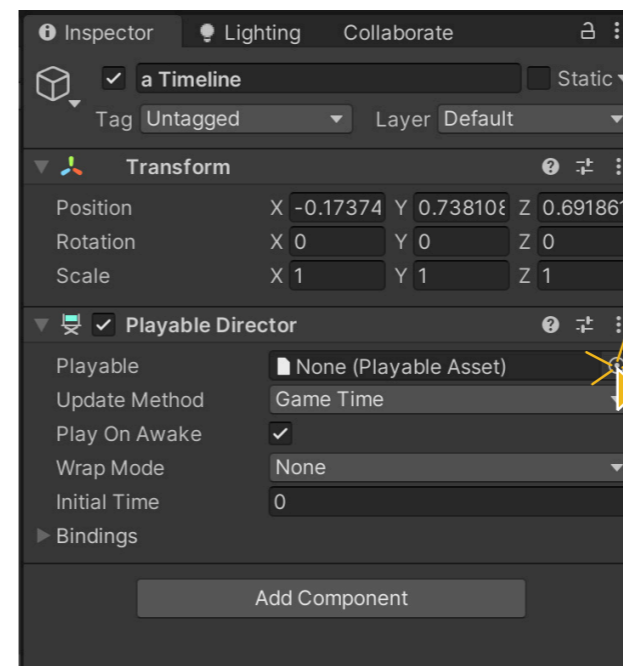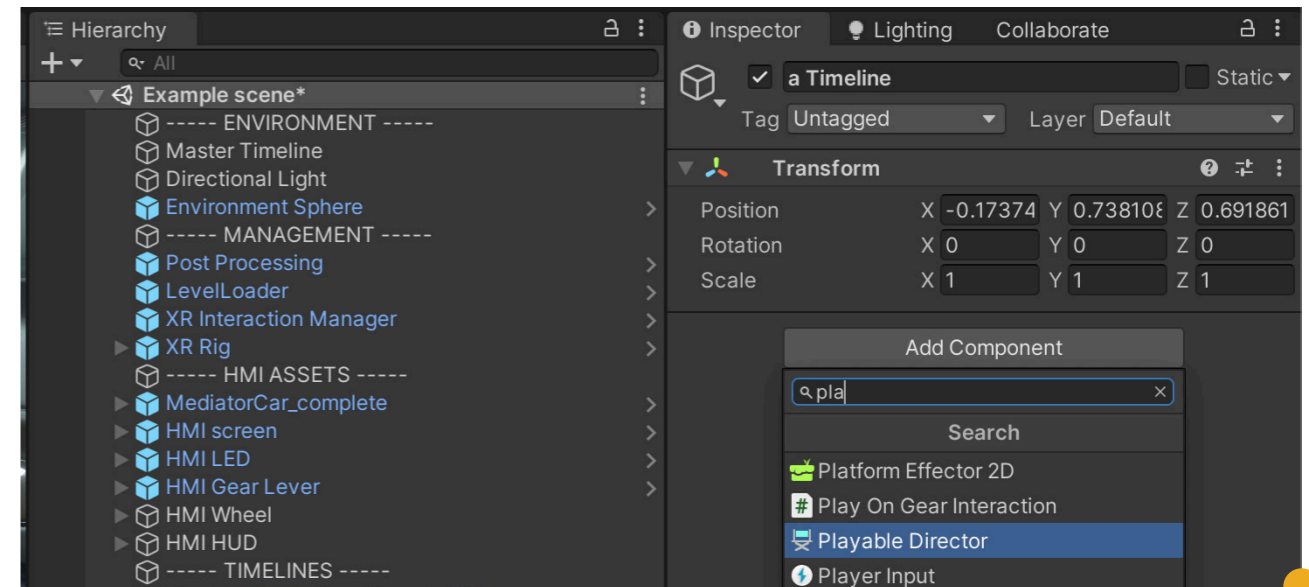
Select the new empty object and click "Add Component" button in the Inspector. Then, add the Playable Director component.

Click the circular icon in the Playable variable field to select a Timeline asset from the ones existing in the project.

Watch the following video to see how you can add these to your scene and create the necessary bindings: **Adding Timeline Assets to the Scene**

(https://swov2.sharepoint.com/:f:/r/MEDIATOR/Shared%20Documents/SWOV%20intern%20-%20onderzoek/WP1/T1.5/Time%20budget%20concept/Anna/User%20Manual%20-%20Mediator%20VR%20Evaluation%20tool/Video%20Tutorials?csf=1&web=1)

CONTROLLING TIMELINES

Once you have added the desired Timeline assets to your Scene, you must decide when and how they should be played during the evaluation.

You can choose **two methods** to control the Timelines in your scene:

1. **Timeline Controller - Wizard of Oz component:** This is an object that can be added to the Scene, which includes a script that allows you to define which keyboard keys you can use to manually play (or pause) a Timeline during the evaluation. Each timeline will correspond to a single keyboard key.
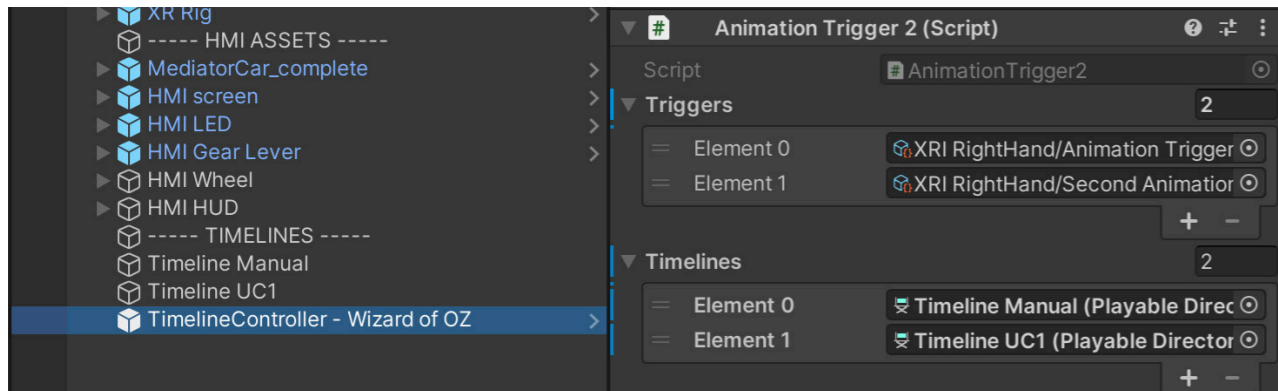
If you would like to manually activate the Timelines which you added to the Scene, drag the *Timeline controller - Wizard of Oz prefab* into the Hierarchy. You can retrieve this prefabs from: **Project > Assets > System Prefabs**

Next, you can set up the keys in the order which you would like to activate the Timelines. **Adjust the length of the Triggers and Timelines list to fit the number of Timeline assets which you would like to activate manually** (this can include a Master Timeline).

Finally, you can **add your Timelines to the list**, as shown in the next image. **In the Triggers list, you must assign the keyboard inputs, which are created using Unity's Input Action System**. A number of keys for controlling the Timelines are predefined, see pages 35 and 38. If you would like to access more information about the Input Action System, please visit: https://docs.unity3d.com/Packages/com.unity.inputsystem@1.0/manual/QuickStartGuide.html

Note: To prevent the Timeline asstes to automatically play at the start of the application, make sure to **untick the Play on Awake option** in the Playable Director component.

Double click the number box and input a new number to edit the size of the list.

Click the circular icon of the list element to select a Timeline object. Each element in the Triggers list affects the element of the same number in the Timelines list.

Note: Each input key selected in the Triggers list will affect the Timeline object that is added in the same position in the Timelines list.

2. **Master Timeline:** If you would like your Timelines to be played automatically in a specific order, you can arrange them on the time axis of a new Master timeline. By using the Control Track type, each timeline in the Scene will be played at the desired time.
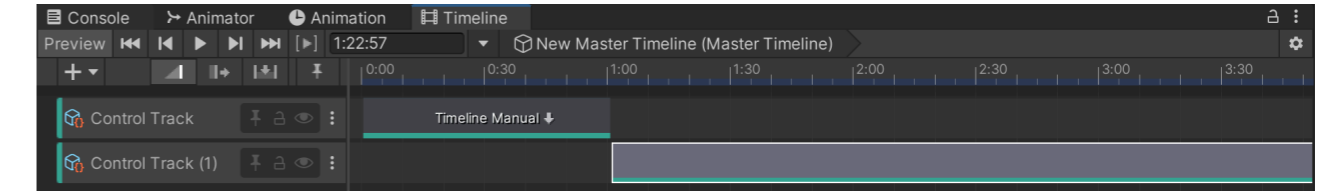
To set up a Master Timeline **create an empty gameObject in the Hierarchy**. Then, select the object and **navigate to the Timeline Editor and click *Create***, as shown in the image on the left. You now have an empty Timeline.

Clicking the Create button will create a Timeline asset and add a Playable Director to the object that is selected.

Drag the other Timeline objects to the Editor, a new Control track will be created. Do this for all of the desired Timelines and arranged them on the time axis.

In the following video you can see how to us each method and set up your timeline control: **Controlling Timelines**

(https://swov2.sharepoint.com/:f:/r/MEDIATOR/Shared%20Documents/SWOV%20intern%20-%20onderzoek/WP1/T1.5/Time%20budget%20concept/Anna/User%20Manual%20-%20Mediator%20VR%20Evaluation%20tool/Video%20Tutorials?csf=1&web=1)

MODIFYING TIMELINES AND ANIMATIONS

If you would like to modify a Timeline, you can do so by playing with the position and duration of the Clips in the Timeline editor. For greater changes, you can also modify animation clips, or create new ones using the record function.

> **Note:** changes made to an existing Timeline asset will be automatically saved. To avoid overriding the existing asset across the entire project, you can **duplicate it by selecting in the Project Folder and clicking Ctrl+D** (or command+D on MacOS).

Timelines are constructed of different tracks which define the animation of the various HMI objects existing in our Scene. On each we can add one or more **Override tracks**, these **allow us to play multiple animation clips, of the same HMI object,** at the same time. The two animations will merge together.
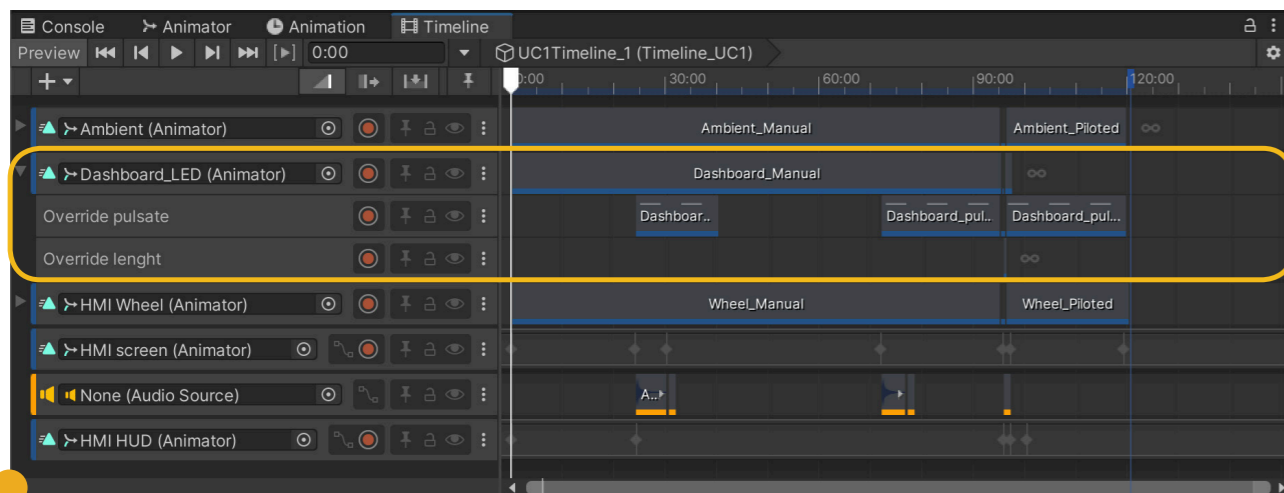
The Dashboard_LED animation track has two override tracks. The main track is used to define the color of the LED strip. The override tracks devine the pulsating effect and the lenght.

Animation clips can be positioned at any point on the timeline axis. We can extend an animation clip by clicking and dragging from the start or the end of a clip. This will extend the period in which the animation will play, **being looped for the length of the clip.**
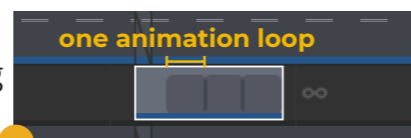
Visual representation of animation loops in the Timeline Editor.

Different animation clips can be overlapped on the tracks. This will create a smooth transition between the two states.
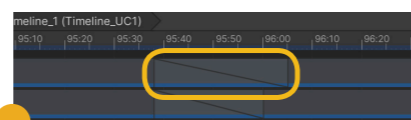

Two animation clips overlaping.

If we wish to extend the time that a single loop will take to complete we must modify the Speed Multiplier variable in the Inspector window.

The **post-extrapolate and pre-extrapolate variables define what will happen before and after an animation clip is played** in the Timeline. If we want our object to maintain the changes that are applied after the animation clip has ended we can select Hold on the post-extrapolate variable. This will preserve the object in the state it is in on the last frame of the animation clip. If we select to Hold on the pre-extrapolate variable, the object will appear in the state of the first frame of the clip before it starts to play.

Animations can be recorded directly onto the Timeline asset and will look like the image below. By clicking the record button on each animation track and applying changes to the object linked to the track we can create new animations.
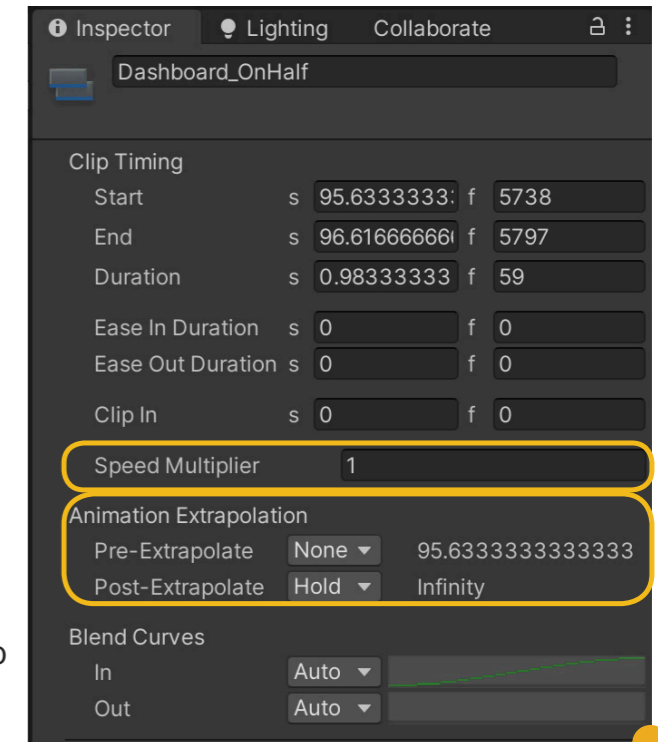
Speed Multiplier and Animation Extrapolation options in the Inspector.
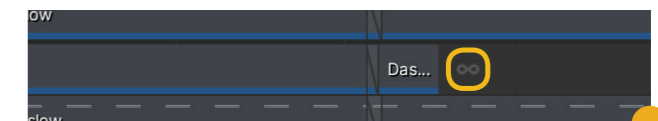
Visual representation of the Hold exrapolate option in the Timeline Editor. It will apprear before (pre-extrapolate) or after (post-extrapolate) the animation clip it is applied to.

To record animations, press the highlighted record button. Recorded animations show keyframes on the timeline axis. Double clicking the track will open the animations window, where keyframes can be modified.

> In the video you can see how Timelines can be modified to fit your experiment: **Modifying Timelines and Animations**
>
> (https://swov2.sharepoint.com/:f:/r/MEDIATOR/Shared%20Documents/SWOV%20intern%20-%20onderzoek/WP1/T1.5/Time%20budget%20concept/Anna/User%20Manual%20-%20Mediator%20VR%20Evaluation%20tool/Video%20Tutorials?csf=1&web=1)

4 Building Evaluation Scenes

Once you have created all of the scenes required for your experiment, you must build the scenes onto the VR device.

Our project includes an object named Level Loader. This is an empty object to which we have attached a script that we can use to define a set of keyboard keys that will start the various Scenes we have built, during the evaluation. This component allows up to remotely start a Scene while a test participant is wearing the VR headset and be in control of the experiment.

In order for our Level Loader to work properly, we must set it up in the Inspector (selecting the Level Loader object) and in Unity's Build Settings: **File > Build Settings...**

BUILDING THE PROTOTYPE
First, open the Build Settings window, as shown in the image below. In the Build Settings window we can see a list of "Scenes In Build". Here, **we can add the scenes in our project that we would like to use during our evaluation**.

On the right we can see that the lists are associated to numbers from 0 onward. This
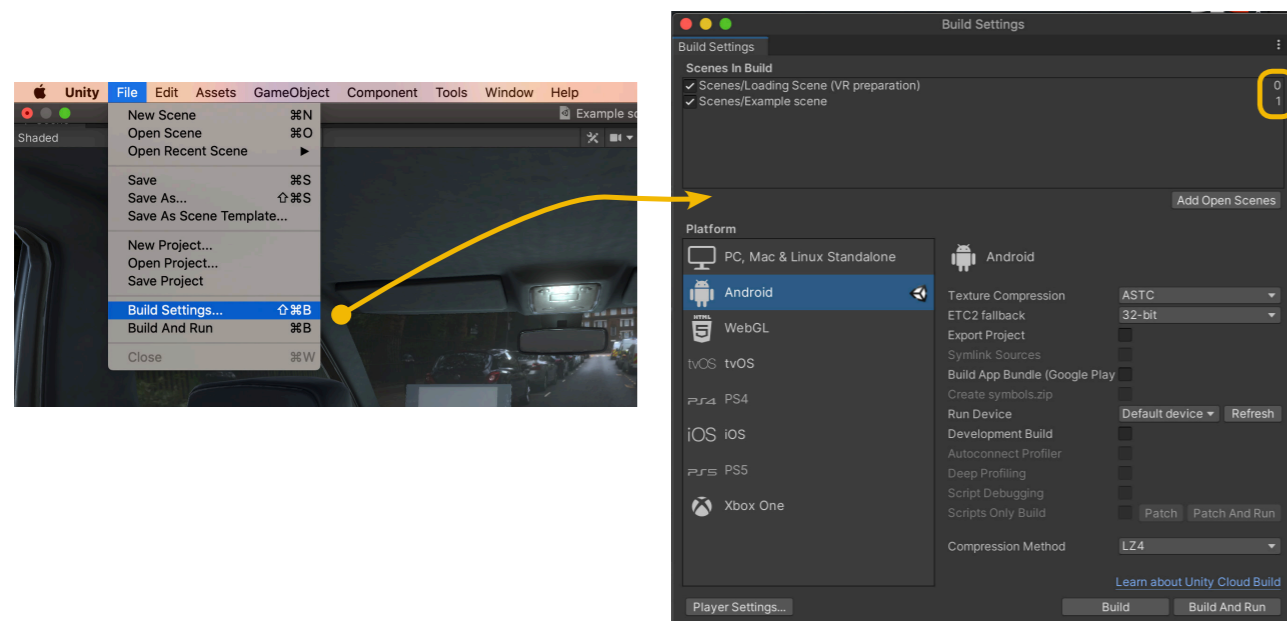
is the order of our built scenes. When starting the application on our device **scene 0 in the list will be the first to play**.

> **Note:** As you will notice in the image, the first scene that is added to out build list is the **"Loading Scene (VR preparation)" scene.** This is a scene that we will use to introduce the test participants to the VR experience and should always be included in your builds and it should always be placed as number 0 in the list.More information on the use of the loading scene in the next section of the User manual.

Once we have arranged our scenes in the desired order, we can verify the remote controls, that will allow us to switch scenes by pressing specific keys on our keyboard, using the **Level Loader prefab**.
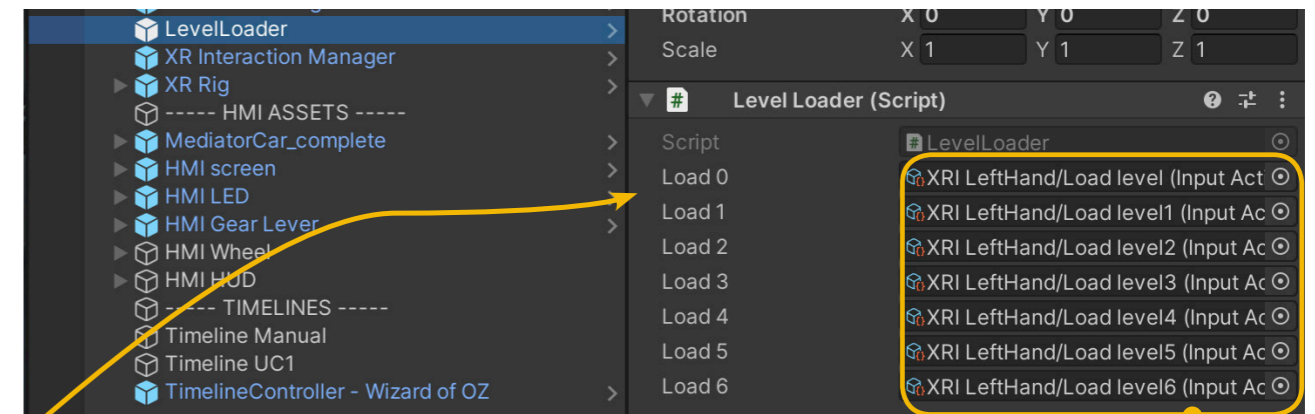
The script attached to this prefab contains a list of keyboard inputs, that allows us to activate various scenes in our list. **Each input, corresponds to the scene that is positioned on the equilavent number in the Build Setting list.**

Key inputs are defined using Unity's Input Action System. Currently, **scenes 1 - 6 in the liscan be activate by pressing keys Q - Y, while scene 0 can de started by pressing Enter on they keyboard. (See page XX)**
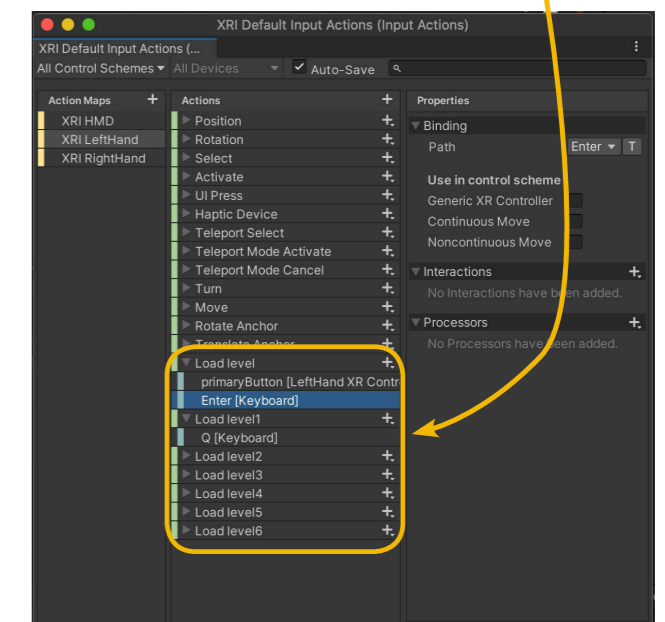
To learn more about the **Input Action System** and define new input keys for activating your scenes you can visit: https://docs.unity3d.com/Packages/com.unity.inputsystem@1.0/manual/QuickStartGuide.html

Using the VR tool During the Evaluation Moment

5

This section includes a number of tips for the use of the Mediator VR Evaluation Tool, during the evaluation moment.

When using a VR device during an evaluation, it is important to **take some time to prepare the test participants for the experience**, as explained in subsections 1 and 2.

In subsection 3, a short explanation of the Wizard-of-Oz controls is given, with **cheat sheet of the existing keyboard controls**.
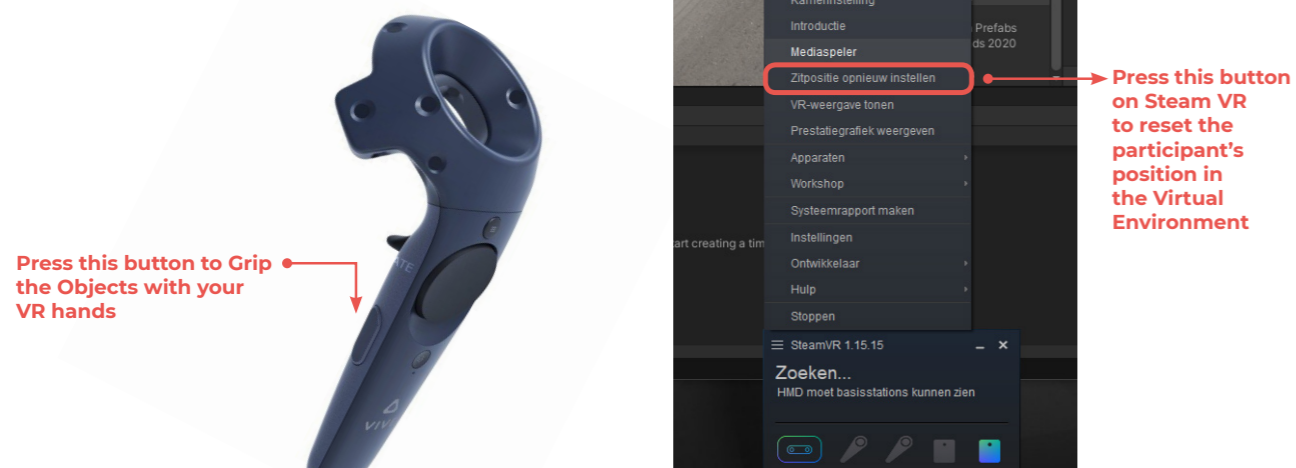
1. INTRODUCE THE VR DEVICE

Before starting the evaluation we must introduce participants to the VR device, explaining how they can comfortably position it on their head and how to use the VR controllers to interact with the virtual environment.

The images below show the buttons which are used to perform interaction within the Mediator VR application on the controllers of the HTC Vive and Oculus Quest 2, the two platforms which were used in the development of this project.

If the participant's position on the virtual car seat is not correct when they place the VR headset on their head, **you must reset their starting position as shown below** (for the HTC Vive) **or instruct them on how to do it** (for the Oculus Quest).

HTC Vive Pro

Press this button to Grip the Objects with your VR hands

Press this button on Steam VR to reset the participant's position in the Virtual Environment

Oculus Quest 2

Press this button for 3 seconds to reset your position in the Virtual Environment

Press these buttons to Grip the Objects with your VR hands

2. VR PREPARATION SCENE

When building our project it is important to remember to include the **"Loading Scene (VR preparation)"**, which, as the name suggests, is a scene that we use to introduce the test participants to the VR experience.

In this scene, which include the vehicle, but none of the details related to the Mediator HMI design, **participants can:**

1. Adjust their headset to get comfortable in VR

2. Reset (or have it done by the researcher) their position in the virtual environment

3. Try out the interactions with the wheel and shifter.

Preview of the "Loading scene (VR Preparartion)

2. USING WIZARD-OF-OZ CONTROLS

The keyboard inputs witch are already setup in the project to **trigger animations and load different Scenes**, were briefly introduced on pages 30 and 35.

The image below shows **a map of the keyboard**, which you can use as a reference to help you and using the correct keys for the desired actions.

Keys defined as "Animation triggers" which can be used in the Timeline Controller - Wizard of OZ object.

Keys used to load the Scenes according to the order defined in the Build Settings:
Q = Scene 1
W= Scene 2
E = Scene 3
...

Key to load the Loading Scene (VR preparation), defined as scene 0 in Build Settings.

Author:
Anna Aldea

Mediator

SWOV

TUDelft

Appendix 8 : Evaluation Materials VR tool

Experiment Introduction

Thank you for taking part in this study. The purpose of this study is to validate the use the Mediator VR Evaluation Tool, as an effective tool in for the evaluation of the Mediator Human-Machine-Interface.

In this experiment we look into the future, and imagine that you are in a self-driving car. The aim of self-driving cars is to take over the driving task from the driver. But, before they can do this completely and under any circumstance, there will be a time in which the drivers will use semi-autonomous vehicles. While these vehicles are on the road a driver must be present at all times to take over the driving task when needed. The driver therefore has the task of supervising the automation and take control within seconds if requested by the automation. The degree of control the driver has over the autonomous vehicle at each time is dictated by the level of automation that is available.
The Mediator system includes **four driving modes**, ranging from manual driving, during which the drive has full control of the vehicle, to highly automated driving, during which the driver is not required to motion the driving task for a specified amount of time.

The Mediator system is designed to inform the driver about the state of the automation (if it is capable of sustaining autonomous driving) and about the current level of automation and is designed to instruct the driver to give over or take over control of the vehicle as needed.

Extra background Information

1. Have you ever experienced COMMERCIAL virtual reality systems? (circle one)

Yes / No

2. Do you have driving experience? If yes, please indicate the number of years of driving experience.

Yes / No   Years: _____

Please think back to the task that was given to you during the experiment: imagining yourself driving a semi-autonomous vehicle, monitoring the information given by the system and interacting with the system to give up control of the driving task.

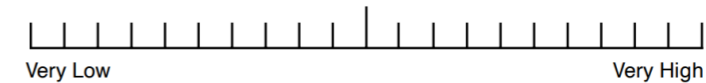On the following sheet, rate the MENTAL WORKLOAD that was required to perform the task described above.

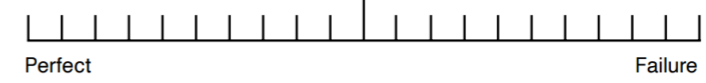**Mental Demand**   How mentally demanding was the task?

Very Low   Very High
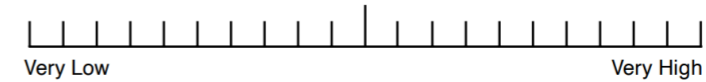
Physical Demand   How physically demanding was the task?

Very Low   Very High

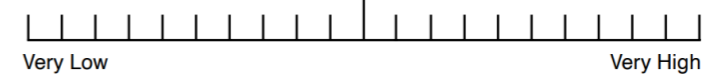**Temporal Demand**   How hurried or rushed was the pace of the task?

Very Low   Very High

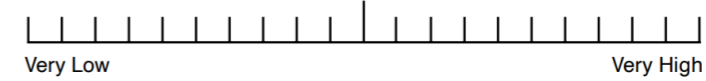**Performance**   How successful were you in accomplishing what you were asked to do?

Perfect   Failure

Effort   How hard did you have to work to accomplish your level of performance?

Very Low   Very High

Frustration   How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low   Very High

_____

Open questions after NASA-TLX questionnaire:

Please elaborate on the given ratings. Which parts of the experience influenced the perceived mental workload of the task?

_____

_____

_____

Please rate your experience of the VR application by ticking one of the circles on the seven point scale between the pairs of contrasting attributes. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

	1	2	3	4	5	6	7	
attractive	○	⊗	○	○	○	○	○	unattractive

This response would mean that you rate the application as more attractive than unattractive.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Please assess the product now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

A third questionnaire was used for the final evaluation of the VR tool: the ICT-Sense of Presence Inventory (Lessiter et al., 2001).

The questionnaire contains XX items related to the user's experience with a form of media (interactive or non-interactive). The items are divided into four factors: **spatial presence, engagement, ecological validity (or naturalness) and negative effects.**

As the questionnaire cannot be publicly shared, an example of one questionnaire item per each of the four categories will be given.

Spatial presence: "I felt I was visiting the placesin the displayed environment."
Engagement: "I felt in-volved (in the displayed environment)."
Ecological Validity: "I had a strong sense that thecharacters and objects were solid."
Negative Effects: "I felt nauseous."

Users must rate each item on a scale from 1-5, where 1 is "highly disagree" and 5 is "highly agree".

Appendix 9 : Evaluation Materials User Manual

Interview questions:

1. During the evaluation, did you ever feel like you were NOT able to experience the various parts of the Mediator HMI (LED strips, screens, gear, etc..) in a realistic way? If yes, what made the experience unrealistic?

2. During the evaluation, did you ever feel distracted from the subject of the evaluation (the Mediator HMI) and unable to understand what you were experiencing? If yes, what distracted you?

3. In your opinion, which aspects of the Virtual Reality application would need to be improved in order to increase your feeling of actually being inside a vehicle?

4. In your opinion, which aspects of the Virtual Reality application could be changed to improve the overall user experience?

User Guide Evaluation Questions

Preliminary questions:

1. Are you familiar with or have you ever used the Unity Game Engine? If yes, to what extent?

   -2: I have never used Unity game engine
   +2: I have used Unity game engine extensively in the past

-2	-1	0	+1	+2
O	O	O	O	O

2. Have you ever used the following types of applications: Game Engines (other than Unity), video editing and animation creation, 3D modelling, digital prototyping? If yes, to what extent and which ones?

   -2: I have not use any of the above mentioned types of applications
   +2: I consistently use several similar applications

-2	-1	0	+1	+2
O	O	O	O	O

   Applications used:

Questionnaire:

1. I achieved what I wanted to achieve with the system
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

2. The way the system worked was immediately clear to me
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

3. The system was not complicated to use
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

4. It was always clear to me what I had to do to use the system
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

5. The information necessary to complete the task was easy to locate
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

6. The information given in the user guide and video tutorials was clear
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

7. I did not need additional information in order to complete the task
   -2: Highly disagree
   +2: Highly agree

-2	-1	0	+1	+2
O	O	O	O	O

Additional questions (follow-up interview):

1. Do you believe that the provided user guide and video tutorials are enough to support you in creating a custom experiment? Why/who not?

   _____

   _____

   _____

   _____

   _____

   _____

   _____

2. In your opinion, what could be improved in the provided user guide and video tutorials?

   _____

   _____

   _____

   _____

   _____

   _____

   _____