EXPERIMENTAL PROCEDURES FOR PRELIMINARY USER CENTRED EVALUATION OF REGIONAL AICRAFT CABIN INTERIORS IN VIRTUAL REALITY

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ABSTRACT

One of the main aims of the Horizon 2020 CASTLE (Cabin System Design Towards Passenger Wellbeing) project is to deliver innovative cabin interiors solutions that maximize the comfort and wellbeing of passengers in the next future. In order to achieve such an ambitious objective, an effective HCD (Human Centred Design) approach has been put in place to derive a Human Response Model based on a holistic assessment of comfort.
Therefore, the overall CASTLE HCD methodology has been conceived to provide different tools and methods to collect data on the impact that the design of each cabin item has on the user from the earliest design stages. One of these tools is represented by the use of 3D mock-ups in Virtual/Augmented Reality environments to capture data on the user's perception and to rate the level of appraisal inspired by the specific design solution.
In this paper we present the experimental procedures for the Human in the loop simulations in Virtual Reality Environment of the Regional Aircraft solutions provided in the CASTLE Project. First, we introduce the overall procedure plan. Then, we describe the work done for the creation of the Virtual Environment for different scenarios (user standing in the cabin, Galley, Lavatory) and for the subjective evaluation of these cabin items.

Keywords: Aircraft Cabin, Product Design, Virtual Reality, Huma in the Loop Simulation

1. INTRODUCTION

The level of appraisal and visual comfort effect that a designed product has on customers is a key success factor in the development of vehicles. Generally, in a growing and interconnected transportation system, the customer is a passenger that is primarily interested in a comfortable journey and in the optimization of the time spent in travelling. Therefore, also in the aircraft cabin interiors the concept of comfort, traditionally focused on the postural and on the noise and vibration reduction, recently started to be enlarged to a wider set of aspects, such as the general appraisal and visual comfort of passengers, as the perception of travelling in a comfortable cabin and the sensation of having a space for working or resting during the journey time.
To be competitive, interiors industries should be able to understand in advance how specific elements and features of the design can impact the well-being of passengers and their in-flight experience. This is a particularly complex journey scenario to evaluate since, there are many factors at play, besides postural and N&V factors. To compound the challenge, the

target of the modelling process is a subjective variable, for example the perceived comfort of the passengers through all durations of the flight.

Several authors have recently worked on the concept of comfort and well-being in commercial and private aircrafts. P. Vink et al. in [1] present and try to find a prioritization criterion in a complete list of possible factors influencing comfort of passengers and, among all the aspects, refer also on soft aspects related to the perception of passengers, including the seat appearance, as influencing the overall wellbeing. Moreover, there are few studies that help in revealing the correlation between the physical characteristic of the cabin items and the perceived comfort. As an example, in [2] the authors endeavour to find the above mentioned correlation through a literature review but, due to the lack of specific literature, they have to rely on studies mainly focused on postural aspects and mostly originated in other domains, such as the automotive domain.
In this paper we propose to investigate the perceived well-being of passengers on board using Virtual Reality to simulate the visualization and the interaction different regional aircraft cabin items at the early design stage as a contribution to the help inform and validate the design approach and concept strategy of the cabin interior.
Overall, Virtual Reality has proven to be an effective tool for the evaluation of interfaces of consumer products or appliances [3], as well for ergonomic workstations [4] and workplaces [5]. Finally, Berg and Vance [6] provide a survey on some challenging industrial applications of Virtual Reality. Authors provide an overall description of the methodological process to be followed in the Virtual Reality approach. The suggested process starts from the definition of the technologies to be used and their requirements, then a 3D model to be used in the Virtual Reality session is provided. Furthermore, an extensive study on how user experience can take advantage of the use of Virtual Reality can be found in [7]. Despite the evidence on the suitability of using VR to evaluate affective aspects and components of comfort and the extensive number of case studies in industry, there are few references of this application of VR in the aircraft cabin interiors domain. In 2005, a survey on the use of Augmented and Virtual Reality in automotive and aerospace sectors explicitly makes a reference to the simulation of cabin interiors to achieve earlier a superior solution, even if limited to the evaluation of appearance and interaction [8]. Nevertheless, such works could not consider the advancements brought today by technological innovations in VR and AR devices, also in terms of reduced intrusiveness, such the ones brought by new generation HMDs and see-through HMDs [9].
The work presented in this paper has been developed in the framework of CASTLE (Cabin Systems Design Toward Passenger Well-being), a project granted under the Horizon 2020 EU's research programme in the framework of the Clean Sky initiative. Clean Sky is the largest European research programme developing innovative, cutting-edge technology for aircraft [10]. The Clean Sky 2 initiative is structured in a number of demonstrators that cover the aeronautical industrial innovation needs for both fixed and rotary wing platforms. During the development of the CASTLE project it is foreseen to provide solutions and prototypes for the Airframe Integrated Technology Demonstrator. In this framework, special attention has been paid to the improvements that can be brought to the cabin interiors, and specifically to the in-flight experience that passengers can expect in the future. The main objective of the project is to conceive, develop, prototype and test cabin interiors solutions following a Human Centred Design (HCD) approach. Therefore, the research approach is focusing on the analysis of the context of use and of the user's requirements, on the generation of evaluation protocols for each cabin item and on the state of the art of the tools and methods for HCD [11].

Given the innovative nature of the project, Virtual Reality has been implemented in CASTLE in order to collect data on the human perception of both the cabin environment and the satisfaction of specific requirements set in the project from the user's point of view.
In the next section the general experimental procedure of the HCD of Regional Aircraft interiors implemented in CASTLE is described. Afterwards, we describe the work done for the creation of the Virtual Environment for different scenarios (user standing in the cabin, Galley, Lavatory) and for the subjective evaluation of these cabin items. Results of a preliminary test campaign conducted in order to validate the process are also presented and discussed.

2. CASTLE HUMAN IN THE LOOP SIMULATION ASSESSMENT - METHODOLOGY FOR EXPERIMENTS IN VIRTUAL REALITY

In the CASTLE Human in the Loop experiments, comfort metrics are evaluated in a virtual environment, in which a proper number and combination of voluntary subjects experience a virtual mock-up of one or more cabin items.
The general methodology is composed of three steps as follows:

- Experimental Planning
- Experimental Execution and Data Collection
- Data analysis and reporting

The experiments start with collection of 3D CAD models, including colour and material features, to be translated from the design domain to the evaluation domain. The different CAD models produced in the framework of the CASTLE project are representative of the cabin items of interest in the project. In CASTLE such items are represented by the seat, the lavatory, the galley, the cabin lining, the Flight Attendant Seat and the stowage bins. The CAD files are processed in order to simplify the hierarchy and to assign the model decomposition level according to the VR visualization and interaction requirements. Finally, these are imported in the simulation platform. For each experiment a scenario and a storyboard of tasks to be simulated in the virtual environment are designed to assess the comfort metrics of one or more cabin items replicated in the specific scenario. Therefore, the preliminary phase consists in the set-up of the Virtual mock-up in a Virtual Reality Environment. At the University of Bologna two different Virtual Reality platforms have been set up for the CASTLE Regional Experiments: The CAVE and the Microsoft Hololens HMD (Head Mounted Display).
The first one is a multiple screens stereoscopic visualization system that immerses the user in a Virtual Environment [12]. It is developed on top of Commercial Off The Shelf (COTS) components and is based on three 2.5 x 1.9 m rear-projected screens, that can be co-planar or tilted, and a floor. The active stereoscopy is enabled through shutter glasses. To allow the cabin environment to be navigated from a first-person perspective by a user moving on the CAVE floor, face and body tracking is implemented by capturing and filtering data provided by a Microsoft Kinect sensor placed in front of the user at the bottom of the CAVE central screen Figure **1**. Tracking of the face is used to update the VR camera's point of view with the actual user's point of view. [13]. An avatar representing the user is introduced in the cabin virtual environment, and the avatar's joints and face position and orientation are linked to the user's ones captured by Kinect, so that avatar replicates the user's movements and gestures. In the right screen, in the lower bottom corner, an exocentric view of the avatar is placed in order to support the user's proprioception. Finally, to simulate interaction with

objects of the virtual environment visual and sound feedbacks are triggered by the system whenever the avatar hurts or touch selected parts of the model, to fake collision.
As anticipated above, the Head Mounted Display used in this experiment is Microsoft^{TM} Hololens^{TM}, the optical see-through head mounted display developed and manufactured by Microsoft^{TM}. This device is implemented in the CASTLE experiments for the subjective assessment of the visual comfort perceived by a single passenger that moves around - without constraints - in the cabin. The Microsoft Hololens is a wireless device and, although not being completely immersive, it allows participants to walk in the cabin.

Figure 1 Participant in the CAVE (Cave Automatic Virtual Environment)

The experimental requirements are refined in order to define user involvement in the experiment and the questionnaires and/or comfort measurement procedures for evaluation assessment. During the second phase, the experiment is run: for each simulation session, at least 20 subjects are expected to be recruited and introduced to the activity. A briefing is provided to users in written form, indicating few information on the test and procedures (without providing clear knowledge on project objectives, not to influence his / her feeling and behaviour during the virtual experience) and an informed consent declaration is signed by the users. The VR experience is lived by the user, after a short training phase. Some physiological metrics may be collected during the experiment and, finally, a questionnaire results the subjective rating evaluation. In the final reporting phase experiment outputs are collected and the data are analysed. Table 1 provides details of each phase and a description of the tasks to be performed and of the documents to be prepared.

CASTLE Human in the loop assessment	
Experimental Planning	Item vs comfort metrics definition
	VR system set up
	Model type and features/configurations
	Storyboard description
	Questionnaire definition for subjective evaluation assessment
	Users to be involved/experimental total timing
Experimental Execution and data collection (for each subject)	Recruitment and Scheduling
	Informed consent signatory
	User training
	Run of the experiment and eventually collection of on line data
	Questionnaire provision to the user and debriefing
Analysis and Reporting	Collection Analysis of data coming from the experiments, in relation of simulation method and objective or subjective ranking
	Reporting

Table 1 – Description of the processes for the Human in the Loop Experiments in VR

Preparatory documents are provided for each experiment, at each phase of the validation process: Training Story, Questionnaire, Invitation Letter and Informed Consent Form.
Five test cases in total, each corresponding to a different simulation scenario, have been planned to analyse all the CASLE cabin items; each scenario corresponds to a different Virtual Reality set up. In this paper we describe in detail the three scenarios as in Table 2. The right column of the table includes the model that have been imported in the corresponding scenario.

Description	**Cabin Items validated**
Overall cabin assessment, with the **user standing** in the cabin (including navigation, seat row ingress/egress) and interacting with the stowage bin	Seat - stowage bin -Lining
Galley assessment, with a user standing in front of it, exploring the model in real dimensions and interacting with it	Galley
Lavatory assessment, with the user standing inside it and exploring the model	Lavatory

Table 2 Test Case definition and connection with cabin items

3. OVERALL CABIN ASSESSMENT, WITH THE USER STANDING IN THE CABIN

In this scenario the aim is to replicate the passengers experience during a specific phase of flight. In detail, it represents the phase in which the passenger approaches his/her seat and interacts with the stowage bin before taking his/her seat.
This scenario has been reconstructed in the CAVE and the virtual environment has been built upon the seat model, the stowage been model and the cabin lining model. 5 seat rows and 5 stowage bins are reproduced in the scene. Some stow bins are open and some are closed. Such modes have been arranged in the fuselage model so that an entire section of the cabin is created. Currently, the surfaces of the cabin items are the actual surfaces produced in the framework of the CASTLE project while the colours. The passenger is standing and can orient his/her sight to the seat row he is going to approach to and to the stowage bin.
Among the different components of comfort we aim at collecting the general visual comfort, as the level of appraisal, the perceived living space comfort, as the level of living space that the passenger estimates at first sight, as well as the interaction comfort, as the level of how he can interact with the cabin knowing the limitations in space through the collision detection features. The collision detection is triggered by collisions between the tracked body and the cabin items and perceived by the passenger through auditory and visual feedbacks. As an example the collision detection is activated for collisions occurring between the forearms and the stowage bin doors as moving yellow lines originating in the collision area (Figure **2**).

The questionnaire is based on a 5-point Likert scale ranging from “strongly disagree” to “strongly agree” and the questions for the general cabin scenario are related to the different cabin items that compose the scenario itself. Participants are asked to answer to the question: “Please, express how much you agree with each statement” for each of the statements in Table 3.

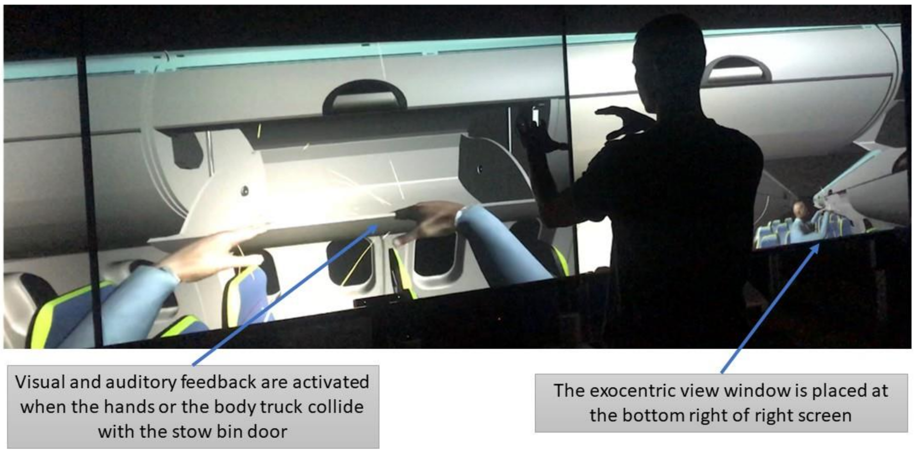

Figure 2 A participant interacting with the Stowage Bin

Statement	Item
The space for accessing the seat and the leg room appeared sufficient	**SEAT**
The seat seemed easy to access	
The seat appeared to have enough space to stretch my legs	
I had the feeling of being in a spacious environment	
I was pleased with the style/aesthetics of the cabin lining	**CABIN LINING**
I had feeling of well-being while walking in the cabin	
I was pleased with the style/aesthetics of the stowage bins	**STOWAGE BIN**
I like the shape design of the stowage bin	
The stowage bin appeared to be spacious enough to easily load my luggage	
The stowage bin seemed easy to reach/use	

Table 3 Cabin Scenario Questionnaire

4. GALLEY ASSESSMENT, WITH A USER STANDING IN FRONT OF THE ITEM

In the Galley scenario a complete Virtual Model of the Galley has been derived from the CAD model. This model has been uploaded in a Microsoft Hololens. The user can explore the Galley and perceive the design in a 1:1 scale mock up projected in 3D (Figure **3**).
The components of comfort to be collected in this scenario are the visual comfort, as the level of appraisal, and the interaction comfort as the user can simulate the reachability of surfaces and items even if without collision feedback.
Since this item is intended to be evaluated both by the passengers and by the cabin crew members the subjective evaluations strategy considers these two points of view. From a cabin crew point of view, the interaction is evaluated, to verify component reachability and cleanability. From a user / passenger perspective, the questionnaire is voted to evaluate design pleasantness and the style of the decorative finishing.
Participants are asked to answer to the question: “Please, express how much you agree with each statement” for each of the statements in Table **4**.

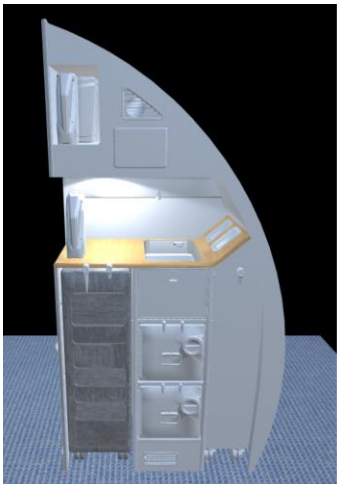

Figure 3 The Virtual Mock up of the Galley

Statement
I was pleased with the style/aesthetics of the galley
The galley equipment appeared easy to reach
The galley appeared easy to clean

Table 4 Galley Scenario Questionnaire

5. LAVATORY ASSESSMENT, WITH THE USER STANDING IN THE LAVATORY

In the lavatory scenario the user also wears the Microsoft Hololens. He initially stands outside a 1:1 scale virtual mock up of the lavatory, steps inside it through the door and explores the environment while standing in this narrow environment (
Figure **4**).
The questionnaire aims to collect a visual feedback of lavatory accessibility and general aesthetic appearance. Questions are also aimed to predict some human factors aspects, as the perception, through the immersion in the mock-up, of being able to operate with the different parts, such as the faucets.
Participants are asked to answer on a five-points Likert scale to the question: “Please, express how much you agree with each statement” for each of the statements in Table 5.

Statement
The lavatory appeared easy to access/exit
I was pleased with the style/aesthetics of the lavatory
The lavatory appeared spacious
The lavatory seemed easy to use
The lavatory space seemed comfortable

Table 5 Lavatory Scenario Questionnaire

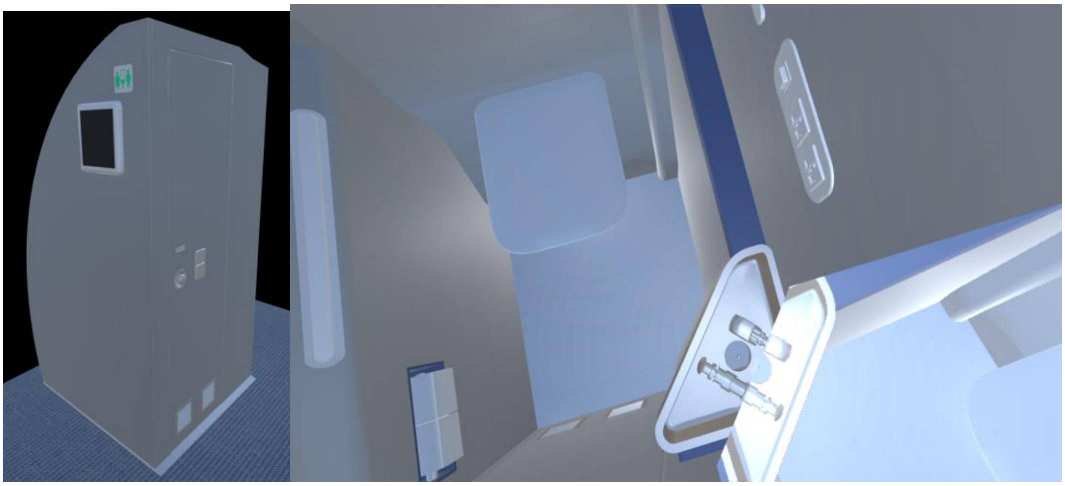

Figure 4 The Virtual Mock up of the Lavatory

6. PRELIMINARY TESTS

A preliminary test campaign has been conducted at the University of Bologna to gather a first set of data and to tune the experimental procedure. 12 subjects, 10 males and 2 females have been recruited among the University students. The average age is 22 years. As depicted in Figure 5 the experiment starts with a brief introduction and the signature of the informed consent. Afterwards, the overall cabin scenario is started in the CAVE. Each participant is trained to the scenario basic features before personally taking part to the experiment. Before starting, the height of the participant is inserted in the system so that the height of the avatar, and therefore of the virtual camera tracked with the Kinect, corresponds to his/her actual height. Once the first scenario is completed, participants are asked to fill the questionnaire concerning the seat and the stow bin. Then, the participant is asked to wear the HOLOLENS and, after a brief training on the system functioning, he experiences the virtual lavatory and the galley, alternatively, and fills the questionnaire. The entire process lasts about 45’.

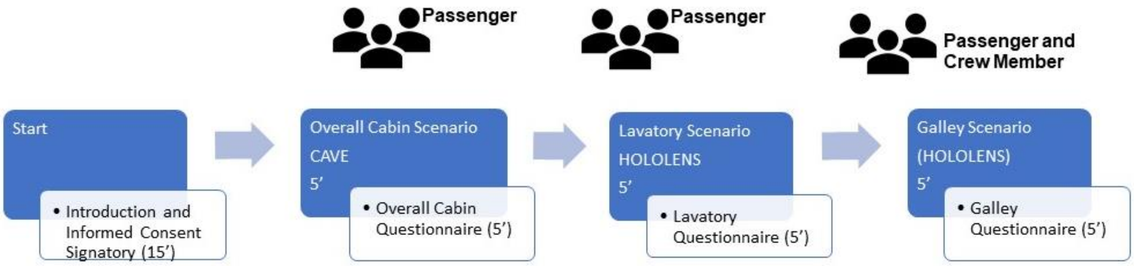

Figure 5 Preliminary test campaign on the CASTLE Regional Jet

Even if the target number of subjects has not yet been collected, this first set of participants allowed us to validate the experimental procedure, to understand if the time assigned to each phase is well estimated and which is the feedback of participants concerning some interaction features specifically designed for CASTLE.

The experimental procedure did not present any specific issue and the time resulted well estimated. The interaction features have been rapidly understood by participants.

In Figure 6 the results of this first set of subjects. These data, besides not comparable with a baseline set of data, can give a general idea of how the cabin is perceived. The Regional Aircraft has a narrower cabin height compared to the most common aircraft that are currently operating the medium range flights. On the one hand, looking at the chart on the "The seat seemed easy to access" we observe that no one reports a "Strongly disagree" or a "Disagree" while 33,3 % and the rest is undecided. On the other hand, in the chart representing the visually perceived space for the legs (legroom), before sitting, 33,3% of participants disagree on the fact that "The seat appeared to have enough space to stretch the legs.

While this first two questions are only based on a visual feedback and thus describe an estimation that the passenger gives of the available space, the questions concerning the stowage bin are supported, in the Virtual Environment, by the collision detection features implemented by tracking the user' body. More than 50 % of subjects (41,7 + 16,7) perceives the stow bin as sufficiently spacious to load the luggage. 16% of subjects strongly agrees and 50 % of subjects agrees that the stow bin is easy to use.

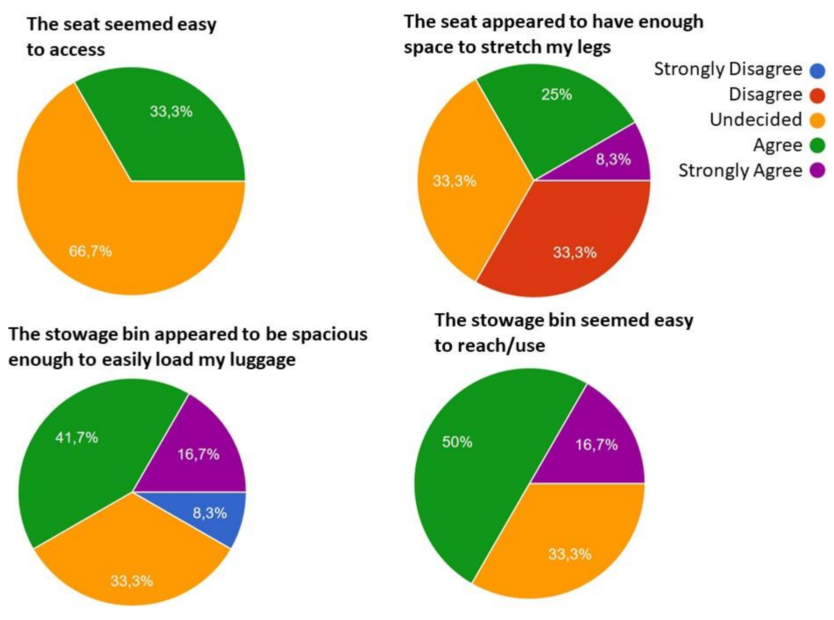

Figure 6 Charts of a selection of questions on the seat and the stowage bin

The response to the questions concerning the style and design of the cabin are not homogeneous and this does not allow to affirm that there is a strong impact. It must be considered that the color and material finishing is still to be implemented.

No specific issue arises from the virtual navigation of the galley, since all the subjects generally report a positive response.

A selection of responses to the lavatory questionnaire is depicted in Figure **7**. Besides 8,3% of subjects that strongly disagree, the majority (25% + 33.3%) respectively strongly agrees or agrees with the fact that the lavatory seems comfortable. The style/aesthetic appearance seems to be appreciated by the majority of subjects. As expected, since the lavatory is a narrow space, 50 % of participants disagrees on the spaciousness. In addition, there is a significant percentage of subjects (41,7%) that is actually "undecided" on this question/statement.

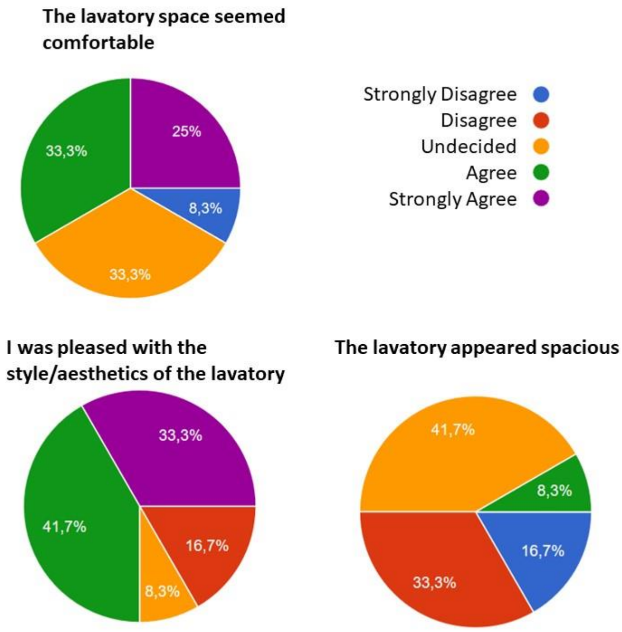

Figure 7 Charts of a selection of questions on the seat and the lavatory

7. CONCLUSIONS

In this paper we present the experimental procedure for the Human in the Loop tests in Virtual Reality developed in the framework of the CASTLE project. In the research project on the aircraft cabin interiors a holistic approach for the evaluation of comfort and wellbeing has been implemented. At the early design stage, before the actual manufacturing of items, this evaluation approach is composed of different tools, primary Virtual Manikins software and Virtual Environments. Besides the former allows to perform exact measures for certain human percentiles on the ergonomics performances, the latter is intended to complement it for a better comprehension of aspects related to the mental process that leads to the positive or negative impact on the human well being given the actual experience of passengers. With this aim, and considering that such mental process has not yet been modelled, the scenarios presented in this papers have been designed in order to capture specific aspects, such as, for example, the sense of comfort or discomfort that we feel when we give a firs sight to the seat that we are approaching to or to the space that we have to allocate our luggage. In addition, the Virtual Environment have been integrated with interaction features specifically designed for this application.

The work represents the research conducted at this stage of the project that includes the study of the tools and methods, the preparation of the Virtual Reality environments, the CAD processing to gather the correct virtual prototypes, the design of the subjective data collection process and the preliminary tests. Therefore, a repeatable methodology for conducting further campaigns and create comparative data is now available.

Even if tests are not intended to gather statistical data, we have discussed the results since this can give an insight in the experimental procedure. Future developments regard the inclusion of colour and material features and the conduction of a definitive campaign with a proper number of subjects.

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