This project has received funding from the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreement no 318483.

D4.2 Second report on the experimentations and evaluations of the 3D-LIVE Tele-Immersive Environment

Deliverable data

Deliverable no & name	**D4.2 Second report on the experimentations and evaluations of the 3D-LIVE Tele-Immersive Environment**
Main Contributors	*UNIVERSITY OF SOUTHAMPTON, ARTS, CENG*
Other Contributors	*CERTH, CYBER LIGHTENING*
Deliverable Nature	
Dissemination level	**PU** – Public – X **PP** – Restricted to other programme participants (including the Commission Services) **RE** – Restricted to a group specified by the consortium (including the Commission Services) **CO** – Confidential, only for members of the consortium (including the Commission Services)
Date	*08/04/2015*
Status	*V1.0, Final for the EC*

Document history

Version	Date	Author /Reviewer	Description
V0.1	09/12/2014	S. Crowle	Initial structure
V0.2	11/12/2014	M. Conte S. Crowle	Updated table of structure
V0.2B	10-16/03/2015	M.Conte S. Crowle	Draft of section 4 Section 5 draft (Golfing and Jogging) T3.6 experimentation write-up
V0.3	18-20/03/2015	B. Poussard S. Crowle	Section 5 draft (Skiing) Section 6 draft (analysis)
V0.4	20-26/03/2015	S. Crowle B. Poussard M. Conte	Section 5 review and updates Section 6 review and updates Section 3 & 4 updates Section 8 draft
V0.5	27-30/03/2015	S. Crowle	Section 4 clean up & updates Section 8 updates Section 9
V0.6	30/03/2015	M. Conte S. Crowle	Updated section 4 Section 8: Methodology feedback update Sections 1 and 9
V0.7	31/03/2015	M. Conte S. Crowle	Updated section 9 Formatting & referencing
V0.8	07/04/2015	S. Crowle	Final updates to sections 8 and 9
V1.0	08/04/2015	S. Crowle	Version 1 final.

TABLE OF CONTENTS

1 Executive Summary

This report presents the final experimental phase conducted as part of the 3D-LIVE project. Technical progress that lead to this final phase includes new developments and refinements to existing work based on lessons learned from previous experimental work (see deliverable D4.1). These early experimental outcomes guided subsequent enhancements to the 3D-LIVE scenarios and the updates to the system prototype. In this final phase of investigation (LIVE 3), the experimental focus has been refined and concentrated on those aspects of the 3D-LIVE UX that most closely aligned with the quality of tele-immersive experience in a shared, mixed reality environment (according to the recommendations received during the Interim Review Meeting).

LIVE 3 experiments were carried out between M26 and M29 of the project. User groups were engaged in a series of experiments that were devised to capture data intended to provide evidence of (anticipated) improvements in the principal dimensions of an immersive UX. Overall, we successfully conducted a total of three trials (one per scenario), engaging 60 participants across 27 experimental runs in total.

In our analysis of the experimental data captured, we compare and contrast the QoE and QoS data generated within and between user groups and scenarios, scoped with specific experimental objectives. As well as reporting on the main user trials, we additionally describe comparisons between high-end, immersive, 3D displays and an evaluation of a network sensitive, adaptive compression algorithm for full body reconstruction data (part of task T3.6). Our analysis reveals generally good to very good QoE responses from our participants in many aspects of their experience; our results provide validation of the 3D-LIVE platform as a system capable of delivering a compelling, mixed reality TI experience. We identify specific QoS influences and game design aspects that impact positively or negatively to overall UX in this context and make recommendations for future improvements of the 3D-LIVE platform. In addition, we propose heuristics for mixed reality system design and implementation. Finally, we provide an analysis of the 3D-LIVE co-creation methodology and its positive contributions to the project, and offer suggestions for its application in other domains.

2 Introduction

2.1 Summary of project

The 3D-LIVE project aims at developing and experimenting on a User Driven Mixed Reality and Immersive (Twilight) platform connected to EXPERIMEDIA facilities (FIRE test-beds) in order to investigate the Future Internet (FI) capacity to support Real-Time immersive situations as well as evaluating both the Quality of Experience (QoE) and Quality of Services (QoS) when users are fully immersed into Future Internet (IoS and IoT) based live (sport) mixed environments. The main objective consists in exploring 3D/Media technologies and Internet of Things in real and virtual environments in order to engage remotely connected users in experimentally driven, live, mixed reality scenarios. The combination of FIRE test-beds and Living Labs would enable both researchers and users to explore Future Internet capacities to enter the Tele-Immersive application market and to establish new requirements for Internet technology and infrastructure. It is expected that combining both FI technology and Tele-Immersion market will promote and accelerate the creation and adoption of innovative sportive events based FI Services by user communities (e.g. sport practitioners).

2.2 Purpose, Scope and Structure

The purpose of this document is to provide the reader with a report of the concluding experimental work that has been carried out in work package 4 of the 3D-LIVE project. This report's scope relates to the final phase of testing of the project's technology platform prototypes for the golfing, jogging and skiing scenarios – these activities are described in tasks T4.3 and T4.4 of the DoW. In this document we review the user experience (UX) assessment methodology; design changes and technical improvements that were made in light of the LIVE2 findings: see sections 3 and 4. Following this, we document the execution of the user trials (section 5) and provide an analysis of those trial (section 6) in order to evaluate final system prototypes. In addition to the LIVE3 user trials, we also describe the experimental evaluation of the network adaptation service (NAS) conducted as part of task T3.6; see section 7. Finally, we draw together the lessons learned from the experimental activities conducted for 3D-LIVE and present the impact our work has had on the direction of future work for tele-immersive, mixed reality systems.

2.3 Related 3D-LIVE documents

D1.2	Study and Create the Holistic User Experience Model
D4.1	Report on the experimentation and evaluations of the 3D-LIVE Tele-Immersive Environment
D3.4	Final prototype of the 3D-LIVE Platform
D5.4	Dissemination and exploitation activity report

3 Approach adopted and rationale of the activities

LIVE 3 experiments activities benefited from the experience accumulated during the previous rounds of experimentation.

The approach undertaken consisted of the following conceptual steps:

1. Updated of specific sporting scenario for the testing purposes. As usual, the scenario were broken down into scenario elements, bringing together homogenous activity relevant to a specific phase of the experience.
2. Focus on the tele-immersiveness part of the UX model. Following a suggestions coming from the EC reviewing team, whose objective was to help us in streamlining the huge amount of information collected during the previous rounds of experimentation, we have been focusing on those part of the model (and relevant metrics) which in our opinion best describe that part of experience related to tele-immersiveness.
3. Instantiation of the UX model (focused on tele-immersiveness) on each specific scenario element, prescribing beforehand the affected metrics as far as QoEs are concerned and proposing a mapping between expected QoEs and QoSs and definition of the relevant evaluation methodology;
4. Planning of the experiments, defining the strategic observations in each case and the objective of each specific runs (or group of runs), such as how UX changes depending if LE or HE set-ups are selected;
5. Execution of the experiments;
6. Evaluation of the experiments, including the assessment of the proposed solutions, the feedback on the designed system and relevant features, the feedback on the scenarios as well as the lessons learnt in terms of adopted design approach.

The present deliverable is indeed organised logically according to what established above.

4 UX assessment methodology

The starting point for the task T4.2 was the update and definition of the methodology to be used to assess the User eXperience.

4.1 Focus on tele-immersiveness – Twilight Model

The focus of the 3D LIVE project was to create an experience for users, so that they could experience the Twilight Zone, and feel themselves like immersed in the mixed environment supported by the 3D LIVE platform. The focus was therefore to understand which element of the designed UX model are directly related to the feeling of being immersed in the sporting action. The objective of that was twofold:

- On one hand, to specifically understand which elements of the User Experience are more directly related to tele-immersiveness;
- On the other hand, to identify which metrics have the most influence and impact on the design of the 3D LIVE systems, so that therefore to streamline their capture and consequent analysis.

In order to achieve that, the elements of the proposed UX model was re-evaluated and the original model was divided in two sections:

- One relevant to the tele-immersiveness constructs and elements, so that to find out the Twilight metrics. Since the main objective of the UX design for TI platform design was declared to make the users feel like they are transported in a new dimension where it is hard to discriminate between reality and virtuality, we decided to identify what is the relevance of each specific UX construct and element of the available UX model with respect of feeling immersed in a new dimension. In other words, we asked ourselves which UX elements and constructs contribute directly to the feeling of being in the Twilight Zone;
- The second relevant to the remainder of constructs and elements. Although not directly contributing to the Twilight experience (which is however a concept which applies to these particular sporting application design, supported by a TI platform), they were anyway extremely useful for the evaluation of the experience as a whole, to provide additional information for the developed system. This set reflects more general concept and evaluation criteria for UX and they are deemed to be easily

extended to other domains, where UX design is required.

The subdivision between tele-immersiveness and other constructs and elements can be better seen later in this chapter, where the different instances of the UX model were reported.

In summary, the main Twilight" Constructs on which we focused for an optimal definition and appraisal of the experience were:

- Social Behaviour, in terms of "Interactions" and "Ties". The more you interact and feel "tied" or connected with the other users, the higher degree of immersion is likely to be happening
- Empathical Behaviour, in terms of Response and relevant "Degree of help/encouragement" and "Degree of support". We believe that this is an extremely important metric, as it complements the mere social behaviour and relates the level of understanding of the other users to the possibility offered by the system;
- Emotional Behaviour, in terms of appraisal of the "Physiological state". This metric measures the level of involvement of a single user, the higher the involvement, the higher is the level of immersion
- Performance related behaviour, in terms of Ergonomics (realism and clearness). Immersion can be obtained only when realism and clearness are achieved, and it is very important to understand the key parameter and how the experience of the users is related to the use of realistic sensors and actuators;
- Exploratory Behaviour, in terms of "Degree of immersion" and "Focus" (Level of Concentration). When immersed in a new sporting experience, the level of immersion is also determined by the "Degree of immersion" (which is quite self-explanatory, meaning with it the subjective assessment on how the user perceive the experience with respect to a reference real scenario) and by the "Focus" (or level of concentration), which is a measure of how much the Tele Immersive environment facilitate the concentration of the users, increasing his/her focus and therefore his/her ability to perform in the twilight environment,
- Actual use, in terms of Frequency and Intensity. Our assumption in the UX model was that if the frequency and intensity of use are high, this is a good indicator that the user can be considered as immersed in the experience. In our model, the frequency of use clearly indicates how many times the user is happy/willing to interact with the system, as an indicator of his/her deep involvement in the

experience, while the intensity of use reflects the user ability/willingness to explore all the features offered by the twilight environment. A good level of immersion is achieved if both these indicators show high values for the same phase of the experience.

4.2 Scenario updates and identification of scenario elements

Based on the outcomes of the previous experiments rounds, the scenarios for the three sporting application were refined, in order to better reflect users expectation while at the same time, propose more credible and smoother activities for the users.

In order to better focus on the user experience (UX), each scenario was divided into phases, or scenario elements, for which all the possible activities where duly identified and characterised in terms of applicable UX metrics.

In terms of the golfing scenario, the following scenario elements were defined:

- Hitting the ball and evaluation of the shots;
- Walking and talking between remote and indoor players and selection of the best ball to proceed with the game.

In terms of the jogging scenario, the following scenario elements were defined:

- Entering the game and reaching the selected point-of-interest;
- Coordinating a quick race to the finish line

In terms of the skiing scenario, the following scenario elements were defined:

- Meeting and greeting users
- Entering the race;
- Racing;
- End of the race: review;

4.3 Qualification of scenario elements in terms of UX elements

The UX Model provides the designer of the experience the “template” on which to describe the different facets of the experience. In order to do that, it needs to be instantiated, in order to correctly depict the specific experience we need to address.

Scenarios were broken down into phases, the so-called scenario elements. Each scenario elements is has a specific focus and characteristics in the game and is described by a specific set of QoE metrics. We instantiated the UX model for each of the scenario elements (or phase), so that to be sure to capture all the details to characterise the experience for that specific phase (it is worth noting that you may have different constructs to deal with depending upon the different needs of the users related to a different phase of the game).

To instantiate the UX model, this meant that, for each of the scenario elements we focused, we needed:

- To select the main constructs and attached QoE metrics among the one offered by the UX model;
- To identify the way how the metrics can be appraised in that specific scenario (by means of both objective and subjective – i.e. questionnaires – means).

Finally, QoE metrics were linked to QoS, to allow for sensitivity analysis, should technological parameters vary. In the following section, we present the assessment objectives for each of the experiments using the UX model, scenario elements and related QoS data.

4.4 Identification of assessment objectives

Experimentation objectives and processes were updated to capture the impact on user experience based on the changes to the scenarios, interaction design and technical implementations. The outcomes of these objectives, when combined, serve to provide us with evidence that allows us to:

- Assess tele-immersiveness of user experience during game-play
- To compare different scenarios (LE/HE) and technologies involved
- To technically validate the final 3D-LIVE prototypes and identify future engineering directions

As already noted, we have chosen to focus more narrowly on selected elements of the 3D-LIVE UX model (see D1.2 for a detailed discussion of the UX model criteria and constructs) that underpin tele-immersive experiences. Specifically, these criteria and constructs are:

- Social behaviour: Interaction and Ties responses
- Empathical behaviour: Help and Support responses
- Emotional behaviour: Physiological states (levels of arousal)

- Performance gains: Hedonic and Ergonomic responses
- Exploratory behaviour: Immersion and Focus responses

The range of 3D-LIVE scenarios allowed us to strategically address our objectives using the range of deployment configurations made possible by the 3D-LIVE platform. In each of the updated use-case scenarios we formed the following mapping:

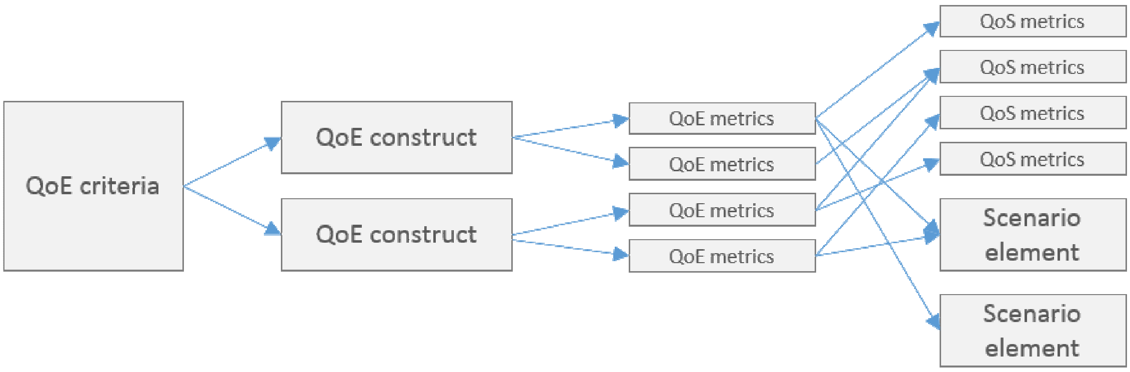

Figure 1: QoE, QoS and scenario element mapping

For the purposes of evaluating the general usability of the 3D-LIVE platform and its potential future use we also included *Technology Adoption* from the UX model in our assessment of user experience. In the following sections we describe this mapping for each of the scenarios and outline the 3D-LIVE platform deployed used to realise the experimental trial.

Golfing specific experiment focus

The golfing scenario is a two player only game that links an outdoor golfer on the Laval course with an indoor user in a LE environment. As indicated, our focus for this experiment was on the UX related to taking and evaluating shots and the social behaviour supported during the walking periods in-between shots. For this reasons we specifically chose to examine the social interactions during the *striking* and *walking* phases.

Jogging specific experiment focus

In the case of the jogging scenario, we were able to deploy both high-end and low-end indoor platforms, using an indoor CAVE environment in Oulu, Finland and a low-end set-up, including full body reconstruction capture, in Thessaloniki, Greece. Our outdoor user followed a short track around the streets of Oulu city centre. In earlier (LIVE 2) experimentation, it was clear that our users enjoyed the competitive element of the jogging scenario. In the updated design of this case we strengthened the social element of preparing for a race by jogging together to a point of interest and coordinating the race start together, then running as fast as possible to the race line. We used this mid-point phase both to strengthen the social UX phase but also to see what (if any) differences could be found related to performance *behaviour/ergonomics* when changing the quality of the full body reconstruction QoS half-way through the race (see section 5.6 for more information).

Skiing specific experiment focus

In contrast to the earlier skiing experiments conducted for this project, the LIVE 2 experimentation scenario, this trial presented users with a significantly changed scenario in terms of its location, scope and user experience. Here, both outdoor and indoor users were provided with a virtual reconstruction of Schladming's Planai I black slope; the scenario was updated with three new social elements; and a change of focus from 'following-the-leader' to a racing game-play was put in place. Again, as part of the drive to improve the social UX aspects of the system, we focussed on social behaviour during the *meeting*, *start of race*, *racing* and *end of race* phases.

In the table below we summarise the UX model/scenario/metrics mappings.

Table 1: Updated UX model with QoE/QoS and scenario elements

QoE Criteria	Construct	Metrics	QoE metric type	Related element of Scenario	Related QoS
Social Behaviour	**Interaction**	Degree of interaction	Likert Scale	Golfing: Striking & walking phases Jogging: All phases Skiing: Meeting; start; race; end	Video analysis : actual social interaction count and duration
	Ties	Connectedness	Likert Scale	Golfing : Striking & walking phases Jogging : All phases Skiing : Meeting; start; race; end	Number of sensory channels used
Empathical Behaviour	**Response (nature)**	Degree of help/encouragement	Likert Scale	Golfing: Whilst users compare shots Jogging: All phases Skiing: All phases	Video analysis : actual social interaction count and duration
		Degree of support	Likert Scale	Golfing: Whilst users compare shots Jogging: All phases Skiing: Meeting; start; race; end	None
Emotional Behaviour	**Response (nature)**	Physiological state	Semantic differential Scale	Golfing: All phases Jogging: All phases Skiing: All phases	Overall level of interaction in game (as a % of game time)
Performance Gains	**Hedonic**	Pleasure	Semantic differential Scale	Golfing : All phases Jogging : All phases Skiing : All phases	None (post game evaluation) Skiing: count of false starts

		Challenge	Semantic differential Scale	Golfing : All phases Jogging : All phases Skiing : All phases	None (post game evaluation)
		Motivation	Semantic differential Scale	Golfing : All phases Jogging : All phases Skiing : All phases	Post experience evaluation and motivation for new experience
	Ergonomics	Clearness	Likert Scale	Golfing: All phases Jogging: Group vs Race phases Skiing: All phases	
		Realism	Likert Scale	Golfing: All phases Jogging: Group vs Race phases Skiing: All phases	Number of sensory channels / Resolution Kinect Full reco PSNR
Exploratory Behaviour	**Immersion**	Degree of immersion	Likert Scale	Golfing: Striking and walking phases Jogging: All phases Skiing: All phases	Position and animation of remote avatars : Skeleton confidence, jerkiness. Full reco PSNR. Avatar positioning: GPS accuracy.
	Focus	Degree of Concentration	Likert Scale	Golfing: Striking phases Jogging: All phases Skiing: All phases	Golfing: comparison of actual strike performance vs real world shot.

Technology Adoption	**Intention to use**	Usefulness	Likert Scale	After the completion of the game	
		Friendliness	Likert Scale	After the completion of the game	
		Confidence	Likert Scale	After the completion of the game	Application frame rate
		Usability	Likert Scale	After the completion of the game	
		Intention	Likert Scale	After the completion of the game	
	Actual use	Frequency	Log: Number of usage	Golfing: Jogging: While running together Skiing: Start/race/end	Video analysis: Count of game interactions with other users
		Intensity	Log: Duration of a session	Golfing: Jogging: While running together Skiing: Start/race/end	

4.1 Representation of UX (in terms of radar graph)

For each user and for each scenario element, we have therefore identified a set of QoE metrics. QoE metrics can be assessed by direct methods (evaluating the response of the users in an “objective” way) or by indirect methods (questionnaires based on Likert Scale, for instance). In this document, we present QoE metrics for a specific scenario element as aggregations in radar style charts, to provide a synthetic overview of UX. QoE metrics for a specific scenario element can be aggregated for more users, to evaluate the stability of the responses.

Different radars obtained from the experimentation (corresponding for instance to two different groups of users, one using LE equipment and another using HE equipment) can be compared, to evaluate how the use of more sophisticated technologies influences the quality of the experience perceived by the users.

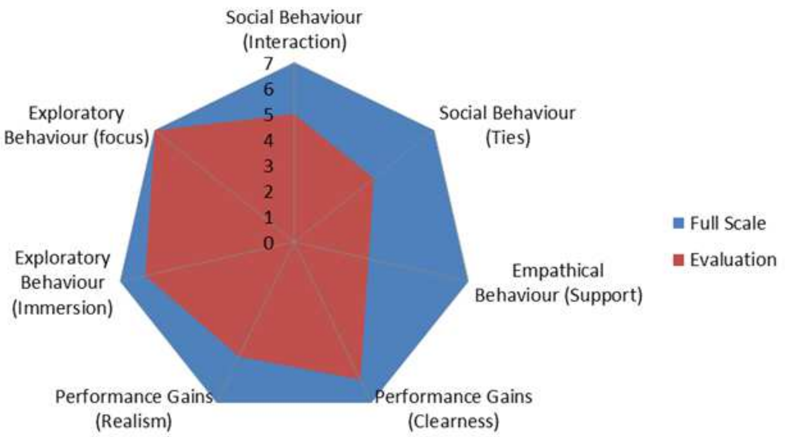

Figure 2: Example of UX evaluation radar

4.2 Technical updates summary

All of the 3D-LIVE prototypes were updated and improved for LIVE 3 deployment. Readers interested in a detailed description of these changes are referred to deliverable D.34. For the sake of brevity, in the table below, we summarise these changes using the matrix representation of changes to the 3D-LIVE platform capabilities and function used in technical deliverable documentation (D3.4).

Table 2: 3D-LIVE traceability matrix (updates to prototype for LIVE3)

ID	Requirement	Priority	Solution proposed	Action taken	Technical outcomes
R2-1	Integrate a HUD for outdoor skiers	1	The Recon Snow2 goggles will be integrated in the 3DLive Ski application. a small display will allow users to see their friends, the rules and the status of the game	See R0-19	The Recon Ski goggles (Snow2) was integrated, allowing users to see avatars, race positions, performances of players and even the virtual mountain.
R2-2	Improve skeleton capturing quality and motion mapping	1	Replace OpenNI with Microsoft Kinect SDK and develop Skeleton Filters	Replaced OpenNI with Microsoft Kinect SDK in 3Dlive Capturer. Additionally developed skeleton filters. This allows smoother animations and more natural postures, even when the user is not properly facing the Kinect (hands in the back for instance). This also allows us to include robust Head tracking to improve the immersion while using HMDs.	The animation quality of the avatars was substantially improved.
R2-3	The jogging activity evaluation algorithm should map scores in a more natural way. Speed recognition should be improved.	1	Review the jogging activity recognition algorithm	Reviewed and updated the Jogging evaluation algorithm. Additionally, added support in 3DLive Capturer for Kinect v2.0 for improved body tracking and thus superior activity recognition results.	Updated algorithm was made more robust; jogging speed estimation also significantly improved.
R2-4	Race on a challenging slope like World Cup slopes	1	The World Cup black slope of the Schladming resort should be integrated in the 3DLive game instead of the garden slope	IT INNOV and ARTS reshaped the skiing scenario with the support of Schladming 2030. IT Innovation provided a new high accuracy 3D model of the slope, and several 3D models of the buildings at the bottom of the Planai I station. ARTS integrated this model in the rendering engine and added the required content to feel on the real slope: trees around,	The new slope has been integrated. A raw model from the GISS in Austria was provided and transformed into a Unity3D terrain. Trees, buildings and necessary details in the environment were modelled to provide enough realism for the Schladming users.

				missing buildings, lift. In addition to that a shader displaying procedural snow on this new terrain was used.	
R2-5	EOS application considered as optional service.	1	For a low-end use the wide area weather data is enough and including EOS set-up added additional complexity/set-up time for end users.		EOS not used in LIVE 3 Ski
R2-6	Avoid unexpected app exit	1	The exit of the app should not be allowed (via coding) and a case should be use to protect the user from unexpected push on the "Home" button of the Android smartphone	The Unity3D java activity has been updated in order to force native functions not to happen when users touch the return button on Android. Moreover a case has been attached to the smart phone to solve the problem of "pressing the Home button"	A security has been implemented to avoid click on "return" button, then a protection case was used to avoid clicking on the "home" button. It worked well, we did not record any other disconnection/exit issue.
R2-7	ERS to match the local weather of the golf course	1	Unfortunately, the Open Weather Map closest station from the golf course in not in Laval, so the weather interpolation can sometimes be wrong.		No way to improve this part of the Golfing scenario in Laval, there is not sufficient data resolution (with specific reference to low-level atmosphere) covered by Open Weather Map data.
R2-8	Avoid inconsistencies and misdetections of the shots outdoors		We identified that despite our tests, iron golf clubs are too ferromagnetic and disturb the IMU sensor. Only carbon golf clubs can be used here	Same as R0-14	Carbon shafts were used. Detections worked better at the beginning of the day. But after a few strikes some problems appeared: sensors drifting / sensors not providing accurate data. EXEL S1 not appropriate for this purpose
R2-9	The Overall setup must be easy and quick	1	A standard configuration for the deployment and IP addresses should be used to limit the configuration time before starting the experience. Joining the game must be quick. Settings will		The deployment configuration has been decided and pre-configured in the apps. A simple start and GO allowed users to joing the game without waiting time

			be set in advance and just pressing one button will connect users to the game		
R2-10	Voice latency must be very low, and not disturb the framerate of the apps	1	Either a work on background threads or changing the voice plugin could solve the issue. Finally we propose to normalise the voice service and use mumble for the three scenarios.	See R0-1	Mumble was finally used, as we did not manage to implement background tasks Unity3D to handle voice compression and transmission on multiple platforms. Mumble was a good option, it is stable, efficient and do not disturb the game at all. We recovered a high framerate in our apps.
R2-11	Make a clear 2D map of the golf course for the golfers to understand where their balls are on the course.		Update the map view with the latest map representation available. Rotate the map 90°, in order to have a "bottom to top" representation, instead of "left to right" representation of the course.	The map view was updated by ARTS, and rotated 90°	The users did not complain anymore and understood easily where their balls were on the course, by reading this 2D map.
R2-12	Harmonise the 3D reconstruction and activity recognition/speed estimation module.	3		The capture frame-rates between the trained model of the activity recognition module and the actual subject in-game were inconsistent when 3d reconstruction was enabled. Make them consistent. When 3d reconstruction was enabled, capturing frame rates would drop to nearly ~12 fps instead of ~30fps. Moving the reconstruction process in a separate thread enabled the skeleton capturing to be performed in 30fps and be consistent with the activity recognition trained model.	The speed estimation worked flawlessly in Jogging LIVE 3
R2-13	Minimize delays of the 3D reconstructed user's transmission to a level that allows real-time	4	Review the RabbitMQ queue characteristics for 3D reconstruction transmission	In this typical issue of a producer-consumer problem where the producer produces packets at higher rates than the consumer can consume, there was a need to update the 3D Reconstruction Network receiver	No more delays were reported from users during LIVE 3 experiments

	interaction			to use a RabbitMQ queue with network characteristics suitable for real-time tele-immersion. Thus, 3D Reconstruction Network receiver was updated to use a RabbitMQ queue that drops all received frames but the last one.	
R2-12	Add ECC logging capabilities to 3DLive Capturer	5	Update the application code to support ECC metric logging to files	Updated 3DLive Capturer code to support logging ECC metrics to log file.	Logging capabilities were successfully integrated
R2-13	Automate the calibration process and enhance the synchronisation between Kinect & Camera.	3	Update the visual quality evaluation algorithm and fix sync issues	Updated 3D Reconstruction's Visual Quality Evaluation algorithm accordingly, fixed the capturing synchronization issues, and integrated it in 3DLive Capturer.	The calibration process was successfully automated (no more manual calibration steps involved) and sync issues were eliminated.
R2-14	3D reconstruction needs to map the actual user orientation.	3	Update the 3D reconstruction rendering code to reflect correct user orientation	Updated Unity3D reconstruction rendering script to mirror 3D Reconstruction accordingly.	3D Reconstruction's rendering was made consistent with user orientation.
R2-1	Develop a more robust capturing platform to avoid system crashes and enhance the user experience	1	Review the application code to fix the bug	Fixed a memory leak in 3DLive Capturer code	The 3DLive Capturer application did not suffer from the same error again

5 LIVE 3 Experimentation: Activities performed

5.1 Introduction

LIVE 3 experimentation was scheduled towards the end of 2014 with a view to capturing user experience and related system performance of the final versions of the 3D-LIVE prototypes, staggered across the final 4 months of the project.

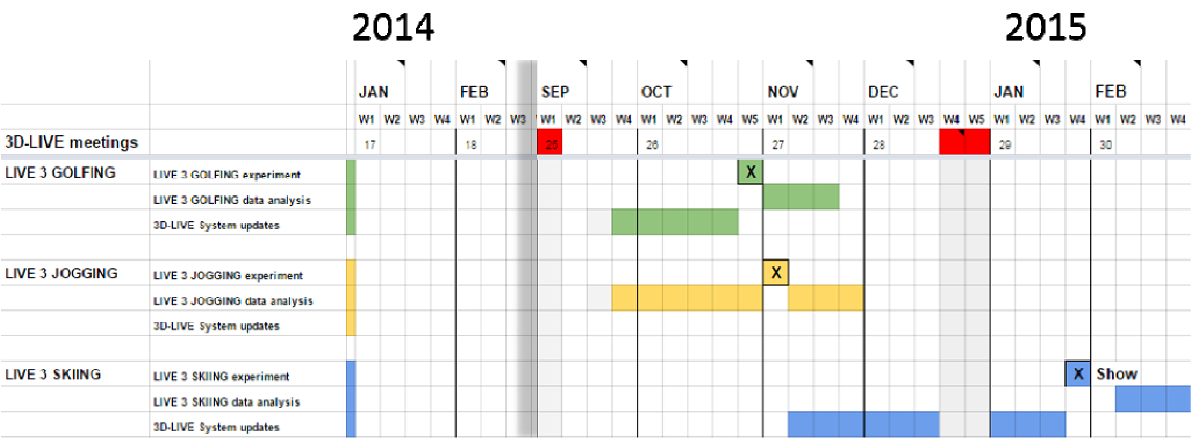

Figure 3: LIVE3 schedule

This final phase of experimentation culminated in the realisation of a significantly updated skiing scenario, a new slope location and novel outdoor/indoor user experiences. During this time the project also hosted two major dissemination activities: coverage of the experimentation by the BBC and, directly after experimentation, live demos presented at the Wearable Technologies Conference, Munich. The impact of this dissemination activity is discussed later in this section; for further information on dissemination activities please refer to D5.3.

Table 3: LIVE3 experiment schedule

Experiment	Execution dates (2014-2015)
LIVE 3 Golfing	27^{th}-30^{th} October, 2014
LIVE 3 Jogging	4^{th}-6^{th} November, 2014
LIVE 3 Skiing	28^{th}-30^{th} January, 2015

Over the course of this final experimental phase, the 3D-LIVE prototypes were continuously refined, and in the case of the skiing scenario, significantly updated both in terms of the scenario design and the technical implementation. In the sections that follow, we present changes made to each of the 3D-LIVE scenarios and prototypes and describe the experimental objectives and activities respectively.

5.2 Experimental design updates

As with our earlier experiments, the experimental methodology required coordinated action between small groups of geographically disparate experiment coordinators and participants. Over the course of LIVE1 and LIVE2 we gained numerous insights into successful patterns for executing these experiments: these lead to a well understood workflow which was applied to the final evaluations (for more information on these methods and a detailed deployment architecture, please see D4.1, section 4). Given this, the design of the experimental design and process received only minor updates relating to the workflow since the design of some of the scenarios had changed. The overall process for experimentation is shown in the figure below.

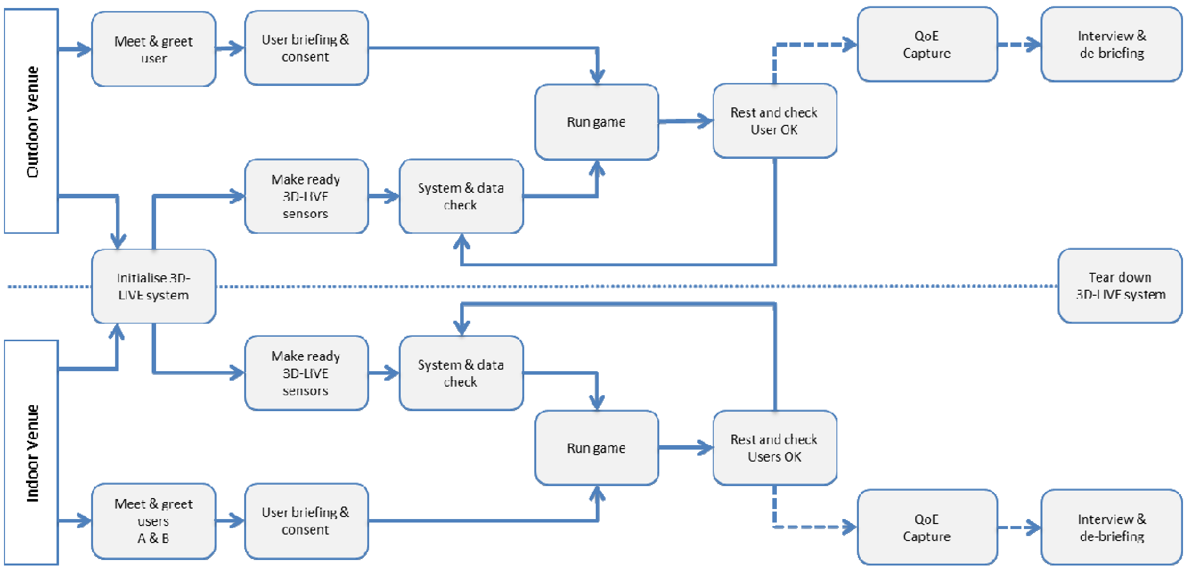

Figure 4: LIVE experimentation workflow

A more detailed view of each of the workflows used in each of the experiments can be found in appendix 10. A summary of the experimental roles adopted by partners is provided in the table below.

Table 4: 3D-LIVE experiment roles

Role type	Responsibilities
Experiment coordinator (IT INNOV)	Handles the over-all coordination of an experimental run through communication with managers and technicians.
Technical coordinators (ARTS/CYBER)	Coordinates the deployment, configuration and initialisation of all 3D-LIVE modules (indoors & outdoors).
Outdoor user managers (IT-INNOV/ARTS/CYBER)	Manages users who are to take part in the outdoor interactions with the 3D-LIVE system. User briefing, consent and de-briefing was required.
Indoor user managers (IT-INNOV/ARTS/CYBER/CERTH)	Manages users who are to take part in the indoor interactions with the 3D-LIVE system. User briefing, consent and de-briefing was required.

In some cases, a project partner (or person) would adopt more than one role if it was practical or necessary to do so.

5.3 User participation

User profiling

Selection and engagement with users for the final experimentation phase was a refinement of the profiles defined in LIVE 2, with a view to capturing the views of users that had a significant level of experience in the specific sport the scenario supported. Our recruitment profile therefore selected from:

- People who actively practice one of the 3D LIVE activities, up to a professional level.
- People who practice the sport and who could be interested experiences that introduce new kinds of technologies and interactions.

To ensure that the different categories were covered, and to manage differences in terms of culture or skills of the users and to maximize user participation in each of the experiment venues, partners of the project started to involve users in their respective country. Consequently French, Greek, Finish and Austrian people, some of whom were professionals in their field, were involved in the process.

Flyers were designed and distributed to communicate about the project around 3D-LIVE partners' organizations, and the website was updated to maintain a link between project members and users. In addition to this, professionals and other venue based stakeholders who were already aware and engaged with the project were contacted and invited to participate in evaluating the latest update of the 3D-LIVE platform.

5.4 Sampling methods

Building on the proven capability of the observational and instrumentation methodology used in LIVE 2, we adopted a similar observational methodology for LIVE 3, namely:

- Automated capture (using EXPERIMEDIA's EXPERImonitor)
- On-line and paper based questionnaire methods
- In-situ 3rd party observations (including still and video image capture)

QoS data relevant to the focussed elements of the UX model were captured from 3D-LIVE technical components using the EXPERimonitor framework; game server logs were also stored. All users were presented with questionnaires that provided us with (anonymised) profile data before the experiment began and then QoE responses to their experience at the conclusion of the trial. Further information regarding the realisation of these methods is provided in D4.1, section 4 and so will not be repeated here.

5.5 Golfing experiment execution

Golfing LIVE 3 at-a-glance	
Date	27th-30th October, 2014

Locations	Indoors and outdoors: Laval, France
Users	9 outdoor players, 9 indoor players (members of the Laval golf course)
3D-LIVE components	Outdoor 3D-LIVE app; golf club motion sensors; Unity game server; EOS outdoor client app; ERS server; ECC server; Indoor 3D-LIVE app; Kinect motion capture.
Experimental runs	9 games

Method

The scenario location was the same used in the LIVE 1 and LIVE 2 experimentation – a single hole at the start of the course, see figure below.

Figure 5: Laval golf course game area

Over the course of 4 days, we carried out a series of games with golfers from the Laval golf course (some of whom were professional level players). Coordination of the experiment was conducted from the IT Innovation UK site whilst the technical management of the 3D-LIVE system was run from ARTS, France. In this case an outdoor user (a member from the Laval golf course volunteered to take on this role) was accompanied by an outdoor user manager (from ARTS) whilst an indoor user (members of the Laval Golf Course or local students recruited by the 3D-LIVE project) engaged with the game indoors at the ARTS site. The experimentation programme was as follows:

- Day 1: Deployment and technical testing
- Day 2: Games 1-3
- Day 3: Games 4-8
- Day 4: Game 9

Data capture

System performance data, taken from instrumented modules of the 3D-LIVE system was captured by the ECC during each game. A summary of the QoS focussed on for this experiment in real-time during the game is summarised in the table below (for a full description of all 3D-LIVE metrics, see appendix B).

Table 5: Golfing LIVE3 core QoS metrics

Module instrumented	**Attributes observed**
1 x Kinect motion capture	Skeleton confidence (%) Skeleton quality (mm) Skeleton Jerkiness X, Y & Z (mm)
Effect Query Service	Effect query rate (requests/minute) Effect type requests (count)
Outdoor low-end application and Indoor low-end application	Frame-rate (fps) Screen resolution (X x Y pixels) Sensor channels (count) Game interactions: shot sent/received GPS accuracy (outdoor user)
Outdoor voice chat module and Indoor voice chat module	Speaker volume (dB) Voice data packets received (count) Voice data bytes received (count) Voice data packets sent (count) Voice data bytes sent
Voice chat metrics	Voice chat packet data sent (bytes) Voice chat packet data received (bytes)

Technical observations

During these technical trials we were able to run most of the games smoothly for the majority of the time. After some teething problems with accessing the 3D-LIVE platform using a new 4G connection, users were able to easily enter the game. Our main problems arose close to the green where we frequently lost 4G connection to the game server. Although this did cause disruption to game play, it was possible to resume the game quickly once players reconnected to the network. We also noted that, during game play, accurate environment conditions were not always possible for two reasons: 1) the wide area current weather conditions captured from the OWM service were providing high level atmosphere data that was mismatched with the ground-level (where it was foggy) and 2) the use of the 4G internet dongle stopped the Android device from providing high precision GPS data to the EOSClient software, meaning that it could not provide location data for the environment samples it was capturing.

User feedback (informal)

When network connectivity was stable, it was clear that users enjoyed the game and were engaged with each other – this was particularly true of users who knew each other. Activity recognition and prediction of shots played by the users were mapped well most of the time, and even when some errors occurred, this did not prevent most users from completing games.

5.6 Jogging experiment execution

Jogging LIVE 3 at-a-glance	
Date	4th-6th November, 2014
Locations	Outdoor and HE Indoor users: Oulu, Finland. Indoor LE + full body reconstruction users: Thessaloniki, Greece.
Users	10 outdoor users; 10 indoor HE users; 10 indoor LE users.
3D-LIVE components	Outdoor 3D-LIVE app; RealXtend game server; ERS server; ECC server; 2 x Indoor 3D-LIVE app; 2 x Kinect motion capture; Full body reconstruction
Experimental circuits	10

Method

As with earlier LIVE jogging experimentation, we virtually and physically placed our users in a subset of Oulu city, providing them a relatively short route to cover that was expected to take approximately 13 minutes to complete if walking.

Figure 6: Oulu running course for LIVE 3

In this experimental deployment coordination was run at IT Innovation, UK. Technical control was managed by CYBER (who control the game service in this case, implemented in RealXtend). Indoor users were situated at the CYBER site (outdoors and within the high-end CAVE environment) and also at CERTH's site, using a low-end configuration that included full-body reconstruction. Experimental monitoring took place at IT Innovation via the EXPERImonitor web based service, whilst other observational data (including video footage) was captured at the indoor sites. This experiment took place over three days, following this programme:

- Day 1: Technical set; testing and runs 1-3
- Day 2: Runs 4-8
- Day 3: Run 9-10

In these trials we took the opportunity to conduct some preliminary tests of varying the quality of the full body reconstruction stream half way through the run. Half the experiments we ran began [1,3, 5, 7, 9] with a high quality full body reconstruction then switch to a low quality stream after all users had met at the mid-way point and the race proper had begun; in the other half [2, 4, 6, 8, 10] we switched the quality settings around.

Data capture

Automatic collection of quality of service data was extended from the LIVE 1 profile with the addition of metrics that captured events relating to full body reconstruction performance and motion data propagation times between users. A summary of the QoS metrics selected for analysis in this experiment is presented below (for a full description of all 3D-LIVE metrics, see appendix B).

Table 6: Jogging LIVE3 core QoS metrics

Module instrumented	Attributes observed
Kinect motion capture	Skeleton confidence (%) Skeleton quality (mm) Skeleton Jerkiness X, Y & Z (mm) Full body reconstruction rate (fps)
Full body reconstruction	Average reconstruction compression time (milliseconds) Average reconstruction compression ratio (Raw : compressed) Average reconstruction frame rate Reconstruction streaming frame rate (fps) Reconstruction vs reference RGB instance PSNR (dB) Reconstruction vs reference RGB sequence PSNR (dB)
Effect Query Service	Effect query rate (requests/minute) Effect type requests (count)
Outdoor user application	Outdoor location (longitude, latitude) Virtual location (x,z coordinates) GPS accuracy (m) GPS update interval (seconds) Display frame rate (fps)

2 x Indoor user application	Virtual locations (longitude, latitude) Display frame rate (fps) Number of avatar collisions (count) Avatar skeleton update throughput (updates/second) Average skeleton data propagation time (milliseconds) GPS propagation delay (milliseconds) GPS propagation delay to display (milliseconds) Full body reconstruction receiving frame rate

Technical observations

During these trials we were pleased to find that we encountered few technical problems with the exception of a few crashes related to the set-up of the Kinect capturer software – this issue was identified, recovered and fixed. Otherwise user motion capture was considered to be good with no problems related to the use of the treadmill. We did note that, in one case, for an indoor users with baggy running trousers, the avatar skeleton reconstruction process was hindered, causing unexpected leg orientation of the avatar in the virtual world. At the beginning of the trails we found that, for a very slow indoor user from Greece, the game engine's physics sub-system did not allow the virtual avatar to mount the pavement due to a lack of inertia. Connectivity with the outdoor user was generally good and there was only one occasion when this was lost (the impact of this was that the outdoor user position was not always updated and voice was disrupted).

User feedback (informal)

Conditions were very cold for the outdoor user and, for some of our outdoor runners, patience ran a little thin when delays caused by technical problems at start-up (and the late arrival of other indoor participants in Greece). Despite this, we observed positive interactions between most of the users during their runs. In particular, we noted that at the mid-way point where players paused to organise the race to the end, users took the time to look around at their surroundings and discuss the look and feel of their virtual environment – which was a significant improvement in social interaction for this scenario.

5.7 Skiing experiment execution

Skiing LIVE 3 at-a-glance	
Date	Jan 28th-30th
Locations	Schladming Austria (outdoors and indoor HE), Thessaloniki, Greece (indoor LE).
Users	6 Outdoor users; 6 HE indoor users; 6 LE indoor users
3D-LIVE components	Outdoor 3D-LIVE HUD app; Outdoor 3D-LIVE game app; Unity game server; ERS server; ECC server; Indoor HE and LE 3D-LIVE apps; Oculus Rift HUD; Kinect motion capture; full body reconstruction.
Experimental runs	8 races (3 users per race) 2 indoor races 2 BBC races (3 users)

Method

Over the course of the three days at Schladming we set up a new 3D-LIVE game deployment and evaluated a series of races with users from a variety of backgrounds. For the first time, the project experimentally deployed game players with head-up displays: outside we used the Recon Snow 2 goggles whilst for the high-end, indoor user an Oculus Rift headset displayed the virtual slope. All users were set up to race down Schladming's Planai I black slope (also used for World Cup skiing events).

Figure 7: Planai I Black run for LIVE 3

The HE indoor user was situated in a hotel room near the actual slope whilst the LE indoor user was situated in Thessaloniki, Greece. Participants were recruited from a small pool of professional and expert skiers at Schladming (whom had a chance to experience both the indoor and outdoor configurations) whilst amateur players (who had little or no experience of skiing) took part in Greece. At the same time we hosted two media organisations who turned up to film and report on our experimentation – these were the BBC and Schladming's local media company who were invited by our hosts, Schladming 2030. They too were interested in actually trying out the 3D-LIVE system (as part of their reporting). Experimentation activities followed this programme:

- Day 1: Technical set-up and testing
- Day 2: Experiments 1-3 + 2 x BBC trial runs
- Day 3: Experiments 4-7 + 2 x indoor races

The overall workflow for this final skiing experiment was similar to the LIVE 2 pattern, but included more scenario elements, based on the updated UX design. Main components of game-play for each race was formed of these elements:

- **Meet and greet the users.** All players met in a specially defined meeting zone (near the bottom lift) where they could see and hear each other. After the players had said hello and were ready to begin, the outdoor user would walk to the lift.
- **At the race start point.** Once the outdoor user had reached the pre-defined starting

point (having ascended to the first exit point on the ski lift) he would use the outdoor 3D-LIVE HUD and mobile applications to navigate to the virtual start line (whilst chatting to the other users, whom would come into view in the virtual world as he approached). Once everybody was in the same physical/virtual space the outdoor user would start the race using the Snow 2 wrist band controller; a short count-down would initialise the beginning of the race.

- **The race.** Users would then proceed down the slope as fast as they could. Indoor users had the option of trying to slalom through virtual gates to avoid time penalties.
- **The end of the race.** Once all users had completed the race (by entering the 'finish zone') they were able to review their racing times and rank. User avatars were placed on a virtual podium to indicate their position.

Data capture

During this experiment, we focussed on a subset of the range of QoS data available from the 3D-LIVE UX model. In the table below, we summarise our QoS focus (for a full description of all 3D-LIVE metrics, see appendix B).

Table 7: Skiing LIVE3 core QoS metrics

Module instrumented	Attributes observed
2 x Kinect motion/FBR capture	Skeleton confidence (%) Skeleton quality (mm) Skeleton Jerkiness X, Y & Z (mm) Average FBR compression time (seconds) Average FBR compression ratio (rational number:1) Average FBR compression frame rate (fps) Average FBR frame rate (fps) Average FBR streaming frame rate (fps) Compressed FBR vs reference RGB (instantaneous PSNR) (dB) Compressed FBR vs reference RGB (sequence PSNR) (dB)

Outdoor LE app	Display frame rate (fps) GPS accuracy (m)
Indoor HE/LE applications	Frame-rate (fps) Screen resolution (X x Y pixels) Sensor channels (count) FBR received frame rate (fps)
Game events	Nominal labels (start of race; in race; end of race) [time-stamped]

Technical observations

As arguably the most technically complex deployment for 3D-LIVE, this skiing platform was the most challenging to set up, so we factored in a significant amount of time to test the configuration and game conditions. During the technical preparation, we discovered that outdoor connectivity dropped out completely just outside the lift where the outdoor player exit to make their way to the start line. Fortunately 4G connectivity was recoverable a little way down the mountain on the way to the start line, so we were able to determine a position where the outdoor application software could be reconnected to the game server and game play could be smoothly resumed. Taking this extra time to prepare for the most complex 3D-LIVE game paid off: we were able to run a series of experiments smoothly and this allowed us to focus on comments from our participants relating to their individual experiences.

During experimental game play we encountered a small number of technical problems, mostly after the end of the race. For example, on one occasion the indoor user full body reconstruction capturer crashed and, outdoors, we discovered on a couple of occasions that the user was either unexpectedly disconnected from the game or no longer able to use the Snow 2 HUD as it had shutdown unexpectedly. These issues notwithstanding, this final 3D-LIVE prototype was sufficiently robust to allow us to run 8 experiments in a coherent and largely predictable manner.

User feedback (informal)

Here are some in-game, direct quotations from our users:

Outdoors, BBC technical correspondent:

“This is incredible … the experience is quite intense … it’s amazing”

Outdoors, experiment participant:

“Wow this is amazing! … I see the mountains on the other side”

Indoors Schladming, experiment participant:

“I will destroy you now!”

Indoors Thessaloniki, experiment participant:

“You are lucky, because I am on a bad day…”

Indoors, BBC technical correspondent:

“It’s just like you’re on the slope”

It was clear that our users really enjoyed the 3D-LIVE skiing experience, both indoors and outside. This is striking as it is important to note that the media presence and filming activities that were included during our experiment days introduced very long delays before races could be run. Under normal conditions, we would expect most users’ attitude to be significantly negatively influenced by these days. As with our LIVE2 findings, we noted that some game players (especially the outdoor user) did not engage in social chat very much during the actual race since their focus was primarily on navigating down a challenging slope: we discuss their perceptions of sociability later in the analysis chapter of this document. There was a clear sense of competitiveness and evidence that users were integrating their personal experience with others during the newly created social phases of the game (at the start of the race and at the end).

6 Analysis of the Golfing Scenario

6.1 Golfing

6.1.1 *Summary of indoor QoE/QoS*

The quality of service measured for the indoor golfers shows that from the technical point of view, some components provided a good performance and some others still require improvement. For instance, the frame-rate of the application was in average 46.6 frames per second which is acceptable but could be further improved for an indoor deployment; indeed we expect to eventually reach a stable value of 60 fps for a smoothest experience. It has been identified that the issue is caused by the use of the Voice-Chat plug-in inside Unity3D; optimising the voice component would likely achieve our goal.

In terms of the UX model *interactivity* mapping, the measurements related to the skeleton information reported a confidence between 0.9 and 1.0; quality of 3.7; and a jerkiness of around 8.0, meaning the skeleton animating the indoor avatar was most of time very accurate and corresponding to the actual movements of the user. This has been confirmed on the video analysis performed after the experiments where the poses of the avatars seem very natural and correct compared to the actual users' poses. The number of queries to the ERS shows the number of updates of the actual weather in the virtual environment and one can see that sufficient updates were performed to keep maximum of consistency of the virtual world with the real world.

More than the technical components observed, the voice interactions frequency and duration give us an indication of the number of interactions and their duration in the game. The duration is in fact the percentage of interactions time compared to the duration of the game. Depending on users this value evolves from 3.3% to 13.6% with an average of 7%. This shows the flow of the game has yet to be fully optimized to allow maximum user interaction; this improvement may have a varying increased impact depending on the people engaged, since interactivity levels are variable.

Table 8: QoS Metrics results for the indoor golfers

	QoS_Interactivity_Speed_Framerate	QoS_Interactivity_Range_VoiceInteractionFrequency	QoS_Interactivity_Range_VoiceInteractionDuration	QoS_Interactivity_Mapping_SkeletonConfidence	QoS_Interactivity_Mapping_Skeleton_quality	QoS_Interactivity_Mapping_SkeletonJerkX	QoS_Interactivity_Mapping_SkeletonJerkY
AV IN	46.6	53.8	7.0	0.9	3.7	7.2	8.9
MAX IN	108.4	134.0	13.6	1.0	3.8	14.5	17.3
MIN IN	33.1	17.0	3.3	0.9	3.5	3.2	3.6
	QoS_Interactivity_Mapping_SkeletonJerkZ	QoS_Interactivity_Mapping_ERSQueryCount	QoS_Interactivity_Mapping_ERSQueryRate	QoS_Interactivity_Mapping_ERSSentCount	QoS_Vividness_Breadth_NumSensoryChannels	QoS_Vividness_Depth_Resolution	
AV IN	8.0	176.3	3.4	151.0	3.0	1280x800	
MAX IN	14.2	237.0	5.1	203.0	3.0		
MIN IN	4.1	27.0	1.9	23.0	3.0		

Looking at the user experience, we focused on two scenario elements – *strike phases* and *walking phases* – these were the foci for our *social behaviour* and *exploratory behaviour* observations; we present summary statistics for these constructs in the tables below for these phases.

During strike phases

Table 9: Indoor - Strike Phases QoE

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Exploratory Behaviour (Immersion)	Exploratory Behaviour (Focus)
Average	5.13	4.44	4.13	5.63
Min	2	2	1	2
Max	7	7	7	7

During walking phases

Table 10: Indoor - Walking Phase QoE

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Exploratory Behaviour (Immersion)
Average	4.44	3.69	3.35
Min	1	1	1
Max	7	6	6

Studying the Social Behaviour

Scores reported for *social behaviour* were 5.13 about the *interactions* and 4.44 about the *ties*, which are quite acceptable values. Indoor golfers reported a good sense of *interactions* and *ties* according to these results. The users felt connected to outdoor golfers and had the feeling it was easy to interact with them or to understand the interactivity during the strike phases. However, it seems that during the walking phases indoor users reported marginally lower *interactions* and *ties* values (4.44 for interactions and 3.69 for ties). This means that they had the feeling it was harder to communicate and to interact with them during that phase. They felt less connected, as if the outdoor avatar got closer only during strike phases.

These results were interesting for the project. Actually the application is designed to reduce the number of interactions during strikes in order to let users concentrate more when they prepare their stroke, and then the gameplay was developed with a view to offering the opportunity to comment on their past or future shots during walking phases. It seems that users are willing to get more engaged in social interactions when there is a true interaction with the game, when they actually have to strike the balls.

Studying Exploratory Behaviour

Examining the *exploratory behaviour* scores (split into *immersion* and *focus* evaluation), the same applies: scores are higher during the strike phases than during the walking phases. During strike phases the *immersion* reported was 4.13, and this value represents the way users felt on the real remote golf course, the way they felt immersed with their remote partner. This shows clearly that the level of immersion is acceptable for indoor users in this configuration but the immersion is less prominent in walking phases showing a score of 3.35. However the *focus* evaluation which only concerns the strike phase, reported very positive value of 5.63. Indeed, indoor users had the feeling they were able to control what they were doing, training for the strike, and control the power of their strikes to adjust the distance they were willing to reach. The process of strike phases indoors is very satisfying for users.

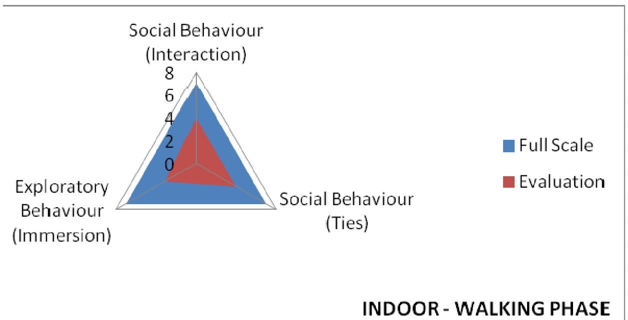

Figure 8: Indoor Golf QOE during walking phases

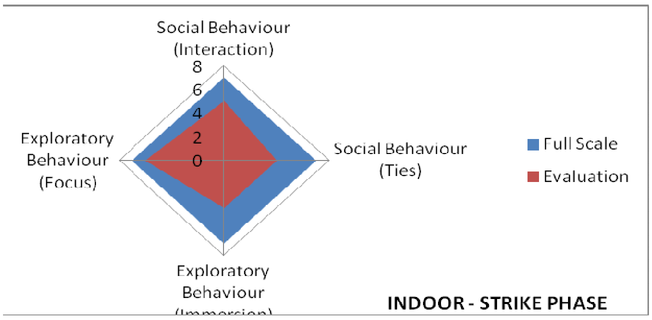

Figure 9: Golf QoE during strike phases

6.1.2 *Summary of outdoor QoE/QoS*

Overall, the QoS measured for outdoor golfers provide us outcomes on remaining technical issues and positive evaluation on components used. The frame-rate of the application was not as high as expected; this was caused by the current voice-chat plugin and is not a solution we can envisage for a commercial deployment in the future as it impacts rendering performance each time users interact. The voice interactions are varying depending on users from 4.7% to 12.6% with an average of 9.2% time compared to the duration of the game. This is still a positive result but still depicts a significant difference depending on users engaged in the game.

The analysis performed on the GPS used reported that the average accuracy of our GPS was 3 meters for an average update rate of 2 seconds. At low speeds in the golfing scenario, this means the avatar represented in the game had a good refresh rate and the ability to be as accurate as the GPS signals. This also means that for ball positioning the accuracy is high enough on the fairway, but the GPS inputs cannot be used reliably account when golfers reach the green area.

Table 11: QoS results for the outdoor golfer

	QoS_Interactivity_Speed_Framerate	QoS_Interactivity_Range_VoiceInteractionFrequency	QoS_Interactivity_Range_VoiceInteractionDuration	QoS_Vividness_Breadth_NumSensoryChannels	QoS_Vividness_Depth_Resolution	QoS_Vividness_SpatialConsistency_GPSAccuracy	QoS_Vividness_SpatialConsistency_GPSRefreshRate
AV OUT	17.2	57.3	9.2	3.0	1920x1128	3.1	2127.1
MAX OUT	60.3	132.0	12.6	3.0		3.3	2606.0
MIN OUT	5.7	27.0	4.7	3.0		3.0	1830.0

Looking at the user experience, we focused on two scenario elements the same way we did for indoor golfers – strike phases and walking phases – for which we observed the *social behaviour* and *exploratory behaviour* elements.

Table 12: Outdoor - Strike Phase QoE

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Exploratory Behaviour (Immersion)	Exploratory Behaviour (Focus)
Average	3.75	4.25	3.68	5.81
Min	1	2	1	4
Max	7	6	6	7

Table 13: Outdoor - Walking Phase QoE

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Exploratory Behaviour (Immersion)
Average	4.56	4.13	3.33
Min	2	2	1
Max	7	6	6

Studying the Social Behaviour

During strike phases outdoor users reported average values of around 3.75 in terms of *social interactions*. This is what we expected because the game is made to disable or reduce interactions and keep the concentration of users at a maximum for the strikes. Users were not able to interact and talk with one another while the remote player was getting ready for the stroke. An interesting outcome here are the *ties* values, which remains quite high (4.25) though outdoor golfers had only one way to remain connected to indoor golfers: the augmented reality view. Indeed, thanks to 3D-LIVE augmented reality, they were able to see the indoor striking the ball. Furthermore it seems that people felt the presence of the remote player through the avatar animated on the AR view of the tablet during strike phases. This result contrasts with some informal remarks we noted during experiments: at the end some outdoor golfers proposed to remove the AR functionality because it takes too much time to play in a synchronous manner on the golf course watching the activity of the indoor player.

During walking phases, correctly anticipated in this case, evaluation of *social interactions* presents higher scores (4.56 in average). Users reported they appreciated talking and interacting a lot with their remote partner while walking to the impact point of balls. Practically, during this phase only the audio interactions are possible between the two players, which could explain why people felt they enjoyed more the social interactions, but on the other hand they felt less connected with the remote player: the feeling of being connected with the remote player on the same shared course, evaluated with the *ties* construct, decreases a bit in the walking phase reaching a score of 4.13 instead of 4.25 for strike phases.

Studying the Exploratory Behaviour

During strike phases the *exploratory behaviour* was evaluated through two constructs – *immersion* and *focus* – as we did for indoor golfers. The immersion reported by outdoor golfers was average (a score of 3.68). Bringing the virtual world to the real world, rendering the avatar of the indoor player in augmented reality for instance, had a mediocre impact as they did not have the right impression that the indoor avatar was actually standing on the real course. Whilst outdoor golfers had mixed perceptions of immersion of a shared virtual golf course, looking at the *focus*, golfers reported they were able to control their interactions with the game, the control of their strikes to reach the game objectives.

During the walking phases, augmented reality was not used as the indoor player's avatar is virtually following the outdoor user, meaning the outdoor should look back to see any representation of the remote user. Consequently the feeling of immersion in one shared space was limited to the audio conversation between players, and the scores reported for *immersion* was 3.33.

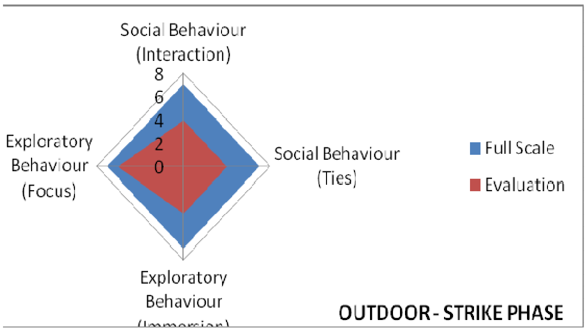

Figure 10: Outdoor QoE during walking phases

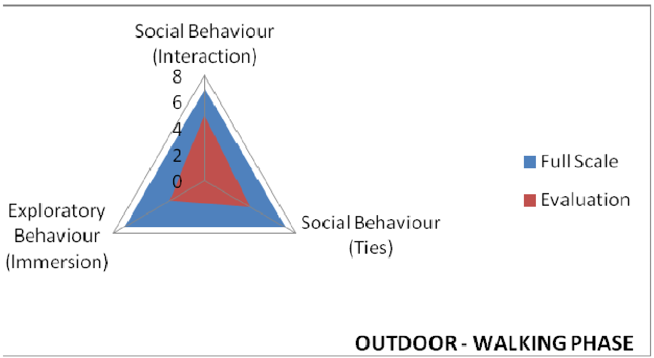

Figure 11: Outdoor QoE during walking phases

6.1.3 *Comparison of indoor vs outdoor QoE*

In Figure 12 one can see that the results, in terms of quality of experience, are quite similar between the two configurations. The *social behaviour* evaluation provided medial scores from 4 to 5. These scores are acceptable despite being attenuated by the problem in the ability they had to communicate. Looking at the informal UX results and the QoS data, it shows that the implemented voice chat plug-in caused latencies and frame-rate issues with the outdoor application and users had some difficulties sometimes to talk with one another.

In terms of *exploratory behaviour*, the two different constructs' evaluation provided very different scores. For *immersion* the score hovers around the middle of the range, meaning both indoor users and outdoor users felt partially immersed with their partner. The GPS accuracy reported was around 3 meters, which is quite good; we believe the sense of sharing one shared environment could be yet improved with higher resolution positioning on the green (when it becomes technically available). Regarding the *focus* construct, representing the ability of the users to control their activity in the virtual environment, while striking the ball for instance, the scores reported were better. The interesting point is that indoor users reported almost the same scores than outdoor users. This means that the system provided an accurate enough set of technologies and interfaces for golfers to focus on their goal, control the power of their strikes depending on the distance to their target.

The *performance gains*: *realism* perceptions reported in the game was 4.21 for indoor users and 3.92 for outdoor users. This construct focused mainly on the realism of the representations of the virtual course and the remote player. One can see that the graphical rendering of the indoor player was representative (but could be improved further) for outdoor players though he was fully animated with a high quality skeleton. Indoor users perceived the representation of the course realistic enough but the evaluation of avatar realism was varying a lot depending on users (scores from 1 to 6). If we compare this score to the skeleton quality reported, the rationale behind these results is related to the switch between live animations and pre-recorded ones. The pre-recorded animations' quality was not high and users did complain about it whereas they did not about live animations.

Finally the *emotional behaviour* of players was evaluated after the experiment. Despite some negative aspects reported, all users mentioned a very good emotional response with values starting from 4.8 and up to 6.5 about the overall experience. This puts the scenario in a position of real potential success if corrective actions proposed by users are taken.

Table 14: Summary of average QoE results for outdoor and indoor golfers

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Exploratory Behaviour (Immersion)	Exploratory Behaviour (Focus)	Performance Gains (Realism)	Emotional Behaviour
Indoor	4.79	4.07	3.74	5.63	4.21	5.6
Outdoor	4.16	4.19	3.51	5.81	3.92	5.52

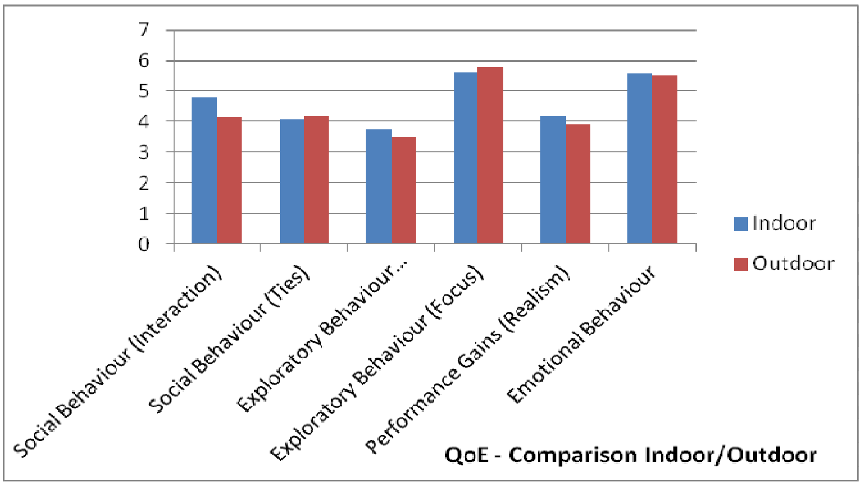

Figure 12: Comparison of QoE results Indoor/Outdoor for the Golf scenario

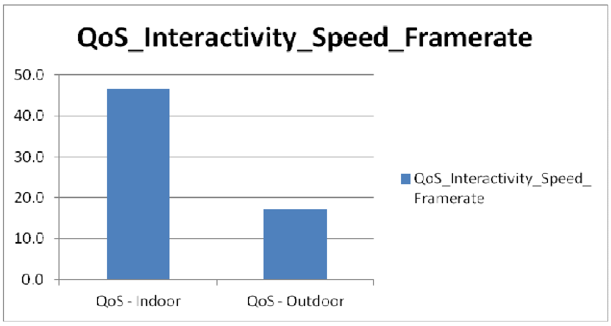

Figure 13: Comparison of QoS frame-rates between indoor and outdoor apps

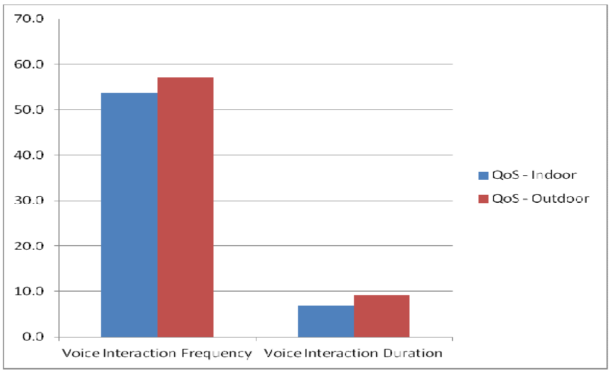

Figure 14: Comparison of Social interactions metrics between Indoor/Outdoor for the golf scenario

6.1.4 *Summary of findings with respect to experimental objectives*

Based on this analysis, we can summarize our findings for the golfing use-case comparing the added value provided by our scenario elements that the setups deployed. Regarding the scenario elements and deployments we will list our main findings in order to think about an improved platform or potential product.

Indoor technical findings:

- Very good skeleton quality: more use in the scenario could lead to better sense of immersion.
- Sufficient environment data to maintain virtual environment
- Voice delays impacted social behaviour UX, which could have been higher

Outdoor technical findings:

- Framerate could be optimised, reducing occasional disruptions to interactivity
- Generally good GPS accuracy: consistency high enough
- Voice delays impacted social behaviour UX, which could have been higher

Scenario Elements findings:

	Walking phases	**Strike phases**
Indoor	- Lower sense of immersion and sense of being able to control their avatar - Medium social interactions, we expected more during walking phases - More attention of users could improve this phase.	- High sense of Focus. Full control over the swings/strikes - Acceptable immersion - Good Social Behaviour. Users feel connected to outdoor users sharing the same activity.
Outdoor	- Lower sense immersion and feelings of being in a shared virtual world. Use of AR avatar to be revisited.	- High sense of Focus. Full control over the swings/strikes - Better immersion, AR presentation to be revisited.

	- Good social interactions and ties	- Good connectedness with other user, but less interactions - Time too long during strike phases watching the indoor golfer

Higher QoE during strike phases for the indoor golfers:

- Better immersion, better social behaviour.
- Users feel more connected to remote players during strike phases, interact more or less with the same intensity but feel they interacted more.
- They feel they have more control on their activity during strike phase.
- They feel their avatar react better to their movements during strike phases

QoE for the outdoor golfers:

- Less sense of immersion on the two scenario elements. Golfers finally reported they might prefer an asynchronous game with indoor users.
- Users feel more connected to remote players during walking phases,
- They feel they have full control on their activity during strike phase.

<u>Indoor application could:</u>

- **Focus on strikes,** like in golf video games. No walking phase as users cannot control and do not feel interest in interactions during walking phases.
- Implement smoother transitions between predefined and **live skeleton animations**, to keep a high feeling of control and immersion.
- Have a **realistic** environment matching real golf course, and realistic avatars.

<u>Outdoor application could:</u>

- **Be transparent for the golfer**. An asynchronous application, reporting scores of remote users but that do not interfere with the actual game on the real course, is suggested.
- Change the Augmented Reality process. The realism and immersion reported thanks to AR could be improved; we could even consider removing this feature from some game phases in the future.

- Have a **realistic** animation of remote avatars if AR is included.

To put it in a nutshell, we learned in the golfing scenario that the voice service must not interfere with the application and that the augmented reality display consumes too many resources in our deployment. In terms of scenario, golfers outdoor must play their game without being overly dependent on indoors users. Indoors must have a continuous feedback of the outdoor user, but focus on strikes to stay immersed and engaged in the game.

6.2 Jogging

6.2.1 *Summary of indoor HE QoE/QoS*

Quality of service measured for the jogging scenario included *interactivity speed* and *mapping* metrics. The observed frame-rate in the application was close to 60 fps in average, which is good and means the rendering was not disturbed by other tasks running. The receiving rate of full body reconstruction mesh was varying from 5.2 to 7.3fps with an average value of 6.0 fps. In a perfect case, this value should be equal to the streaming rate of the indoor LE application. Here the values are a bit lower (streaming at 6.9fps in average), meaning some 3D frames were occasionally dropped in the network. Regarding metrics representing skeleton quality, one can see that confidence on the bones was 0.9 in average. The jerkiness of the avatar is a bit higher than in other scenarios with values around 20mm, but anyways the skeleton is smoothed thanks to jitter filters before the streaming.

Table 15: QoS of the indoor HE jogging configuration

	QoS_Interactivity_Speed_Framerate	QoS_Interactivity_Speed_BodyReconstruction_Receiving Rate	QoS_Interactivity_Mapping_SkeletonConfidence	QoS_Interactivity_Mapping_Skeleton_quality	QoS_Interactivity_Mapping_SkeletonJerkX	QoS_Interactivity_Mapping_SkeletonJerkY	QoS_Interactivity_Mapping_SkeletonJerkZ
AV HE	56.5	6.0	0.9	3.7	17.7	26.9	24.0
MAX HE	58.2	7.3	0.9	3.8	34.1	56.2	47.5
MIN HE	50.4	5.2	0.8	3.5	13.3	12.9	14.3

Looking at the quality of experience, two scenario elements were studied to compare the perception of tele-immersion of users: first users had to run as a group to the mid-point, where they stop to coordinate a race, and then they had a competitive run to the end.

Table 16: QoE Indoor HE Joggers - Running as a group to the mid-point

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Exploratory Behaviour (Immersion)
Average	3.944	4.44	3.56	3.52	4.36
Min	1	1	1	1	1
Max	7	7	7	6	6

Table 17: QoE Indoor HE Joggers - Running to the end

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Exploratory Behaviour (Immersion)
Average	3.94	4.15	3.67	4.11	4.04
Min	1	1	1	1	1
Max	7	7	7	6	7

Studying the Social Behaviour

Interactions scores reported by indoor HE joggers are identical for the two scenario elements. They did not experience any difference in the way they interacted during the game before and after the meeting point. However the connectedness with remote players evaluated thanks to the *ties* score, seems to be higher during the first phase, where users are running together (4.44 for while running as a group to the mid-point / 4.15 while running to the end). The offset is not very clear but can depict the fact users feel more connected when they have a common objective to achieve as a team.

Studying Empathical Behaviour

The *empathical behaviour* corresponds to the feeling to be supportive and to be encouraged by other players during the game. For both scenario elements the average scores of indoor HE users are medium (3.56 and 3.67), meaning they were undecided regarding the remote users' engagement in their own activity or their willingness to encourage other users.

Studying Performance Gains

The *performance gains* reported by indoor HE users is higher in the second phase while they need to run free to the end. The *realism* of the environment and the other players was perceived a bit higher whereas perceptions of the quality of the player's full body representation was not evident in those phases (3.52 for while running as a group to the midpoint / 4.11 while running to the end). Looking in details at the scores provided by each HE user, all reported average good scores for the realism of the environment but all reported lower scores for the realism of the full reconstructed player.

<u>Studying Exploratory Behaviour</u>

Feelings of immersion reported by HE users was higher in the first phase, while joggers are running as a group. This shows the same kind of correlation as for *social behaviour*, and here the score is 4.36 in average while running as a group and 4.04 while running to the end. We are going to compare this result with the scores provided by LE runners, and see if there is a similar correlation reported.

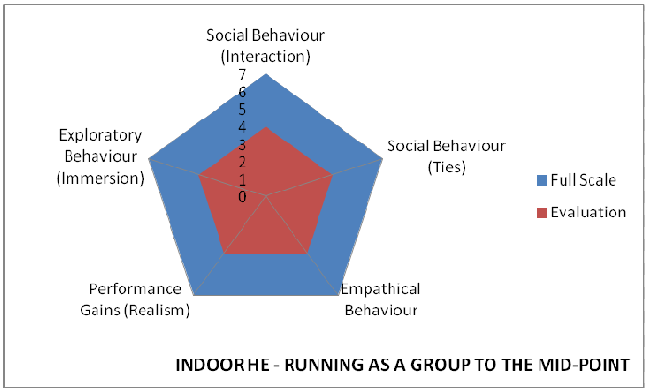

Figure 15: Indoor HE QoE while running as a group

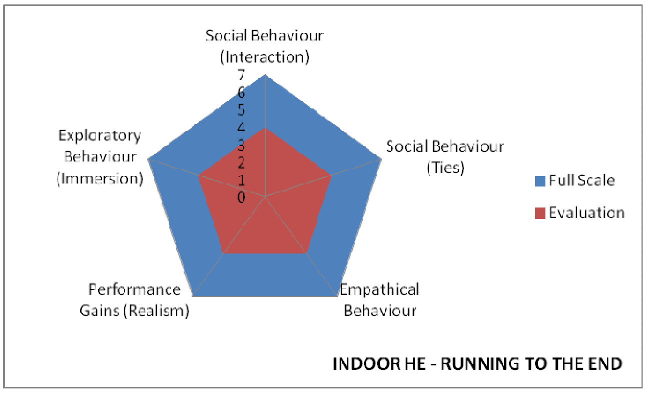

Figure 16: Indoor HE QoE while running free to the end

6.2.2 *Summary of indoor LE QoE/QoS*

The values displayed in the table below are the results of QoS measurements on the indoor low-end (LE) deployment. The main difference in the number of metrics is the fact Full Body Reconstruction meshes were observed and values on their quality, compression rates, transmission rates were reported to the EXPERImonitor.

In terms of frame-rate of the application, there is an unusual phenomenon appearing here. It seems the frame-rates of the applications were very low, starting from 12.2fps for the minimum average value of one indoor LE user and up to 32.7fps for another indoor LE user. These values may impact the UX of indoor runners as values inferior to 25fps cause visible latencies in the rendering.

In terms of the full body reconstruction rate and compression rates, the values are identical and reaching the highest values the module can reach. It means that the performances of this module were at its maximum during Jogging LIVE 3, and that the compression time required to compress packets did not interfere in the full reconstruction pipeline. However values concerning streaming are very close but a bit lower. We further investigate the maximum rate we can get while transmitting such packets using the RabbitMQ protocol without decreasing framerate in section 7. The skeleton quality and confidence values are very good; as are the mapping of the skeleton for indoor LE users. Confidences values were close to 100%, and jerkiness was less than 10mm in average.

Table 18: QoS data summary for indoor LE joggers

	QoS_Interactivity_Speed_Framerate	QoS_Interactivity_Speed_Full Body Reconstruction Rate	QoS_Interactivity_Speed_Full Body Compresion Rate	QoS_Interactivity_Speed_Full Body Streaming Rate	QoS_Interactivity_Speed_BodyReconstruction_Receiving Rate	QoS_Interactivity_Speed_Full Body Reconstruction time	QoS_Interactivity_Mapping_SkeletonConfidence
AV LE	19.7	7.3	7.3	7.2	6.9	0.1	0.9
MAX LE	32.7	8.2	8.1	8.0	7.7	0.1	1.0
MIN LE	12.2	6.3	6.3	6.3	5.5	0.0	0.7
	QoS_Interactivity_Mapping_Skeleton_quality	**QoS_Interactivity_Mapping_SkeletonJerkX**	**QoS_Interactivity_Mapping_SkeletonJerkY**	**QoS_Interactivity_Mapping_SkeletonJerkZ**	**QoS_Interactivity_Mapping_Full Reconstruction RGB Sequence PSNR**	**QoS_Interactivity_Mapping_Full Reconstruction RGB Instant PSNR**	**QoS_Vividness_Depth_Full Reconstruction Ratio**
AV LE	1991.2	5.9	9.0	11.5	16.0	16.0	51.5
MAX LE	5591.3	15.0	17.6	16.5	16.6	16.6	72.3
MIN LE	776.2	0.9	1.2	2.3	13.8	13.9	42.4

The Quality of Experience reported by indoor LE joggers was based on the same model than for indoor HE joggers, as shown in tables [**Errore. L'origine riferimento non è stata trovata.**] and [**Errore. L'origine riferimento non è stata trovata.**].

Table 19: Indoor LE joggers QoE data summary - Running as a group

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Exploratory Behaviour (Immersion)
Average	4.55	4.93	4.05	5.17	5.4
Min	1	2	1	3	3
Max	7	7	7	7	7

Table 20: Indoor LE joggers QoE data summary - Running to the end

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Exploratory Behaviour (Immersion)
Average	4.8	4.9	4.4	5.17	5.3
Min	1	2	1	3	3
Max	7	7	7	7	7

Studying Social Behaviour

Curiously indoor LE joggers reported very different kinds of scores about *social behaviour* indicators. Some users had the feeling to interact a lot and liked it much, so the scores reached the top value of 7, and conversely some joggers reported the lowest scores of 1 or 2. Moreover the scores are not really different between the two scenario elements studied. Overall the average *interactions* evaluation is quite high and acceptable for the target scenario, and the connectedness reported by users through the *ties* scores was seen as good by indoor LE users.

Studying Empathical Behaviour

It seems that indoor LE users got the feeling they encouraged remote users or were encouraged by remote users as they reported an *empathical behaviour* of 4.4.

Studying Performance Gains

The realism perceived by indoor LE users is very interesting. Actually indoor LE users were fully reconstructed in three dimensions in the game and the *realism* they were evaluating was the realism of their own representation. The scores they reported in the questionnaire were quite high and very similar for the two scenario phases. We are going to compare the different scores of *performance gains* depending on the location and the configuration of indoor users a bit later in this section.

Studying Exploratory Behaviour

In the same way, *exploratory behaviour* and sense of *immersion* reported by indoor LE users was very high compared to the deployed configuration they were experiencing, indeed a simple screen was used in the low-end configuration. The main difference was on the full reconstruction impact: indoor LE users saw their own representation in the virtual world. A score of 5.4/5.3 respectively for the two scenario elements depict a good immersion inside the game.

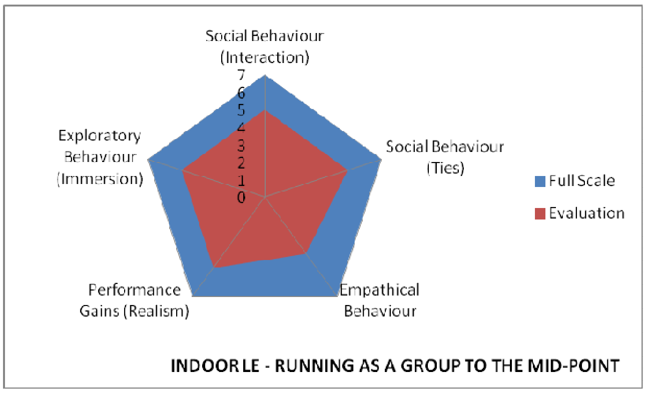

Figure 17: Indoor LE joggers QoE - running as a group

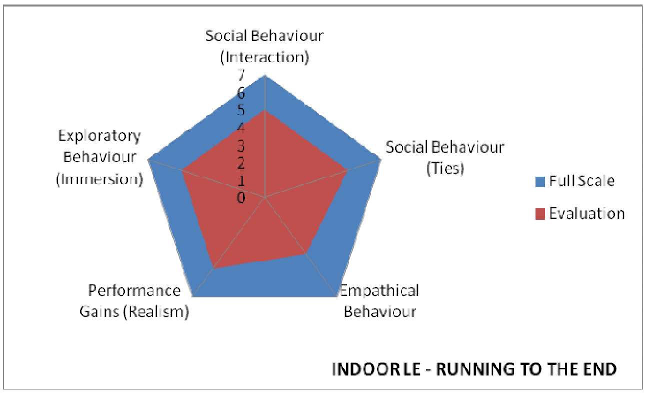

Figure 18: Indoor LE joggers QoE - running to the end

6.2.3 *Summary of outdoor QoE/QoS*

Outdoor joggers had less equipment and technologies embedded in their deployment for the Jogging LIVE3 experiments. Consequently only a few measurements were available; we focused on the overall speed of the application and the spatial consistency metrics, provided by GPS measurements.

One can see in Table 21 that the framerate of the application was high enough for an outdoor application. Conversely the GPS accuracy available in a city town with high buildings was around 13 meters for an average update rate of 1.5 seconds.

Table 21: QoS data summary for outdoor joggers

	QoS_Interactivity_Speed_Framerate	QoS_Vividness_SpatialConsistency_GPSAccuracy	QoS_Vividness_SpatialConsistency_GPSRefreshRate
AV OUT	24.4	13.6	1667.7
MAX OUT	26.6	14.3	2019.1
MIN OUT	22.4	12.3	1415.6

The constructs used to determine the user experience of outdoor joggers were similar to the constructs used for indoor joggers apart from the *performance gains* as no real rendering of avatars and virtual world was performed outside.

Table 22: Outdoor joggers QoE data summary - Running as a group

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Exploratory Behaviour (Immersion)
Average	3.5	3.23	2.75	4.4
Min	1	1	1	1
Max	6	6	5	7

Table 23: Outdoor joggers QoE data summary - Running to the end

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Exploratory Behaviour (Immersion)
Average	3.55	3.13	2.45	4.4
Min	1	1	1	7
Max	6	6	5	1

<u>Studying Social Behaviour</u>

Outdoor users reported an average *interactions* score of 3.5 for the two scenario elements with various scores from 1 to 6 depending on users. It is clear that there was wide range of responses from our users; however this is evidence here that at least some had many interactions with remote players and enjoyed it. For the *ties*, the values are similar and scores vary from 1 to 6 with an average value of 3.1 to 3.2 respectively for the two scenario elements. The connectedness with others could be improved for outdoor joggers in this configuration.

<u>Studying Empathical Behaviour</u>

As we expected, as outdoor users did not feel as connected to other joggers during this experiment, the *empathical behaviour* reported was comparatively low; scores vary from 1 to 5 for an average value of 2.45.

<u>Studying Exploratory Behaviour</u>

The *exploratory behaviour* reported by outdoor joggers is very interesting here. Indeed, outdoor users had a wide range of sense of connected to others; did not interact a great deal; but the perceived *immersion* scores go from 1 to 7 and the average value is 4.44. This means that the relatively low level of equipment deployed allowed at least some users to feel immersed in the same running experience than indoor joggers.

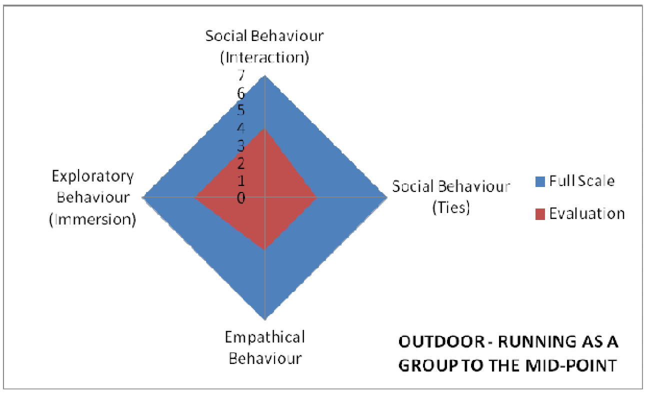

Figure 19: Outdoor joggers QoE - Running as a group

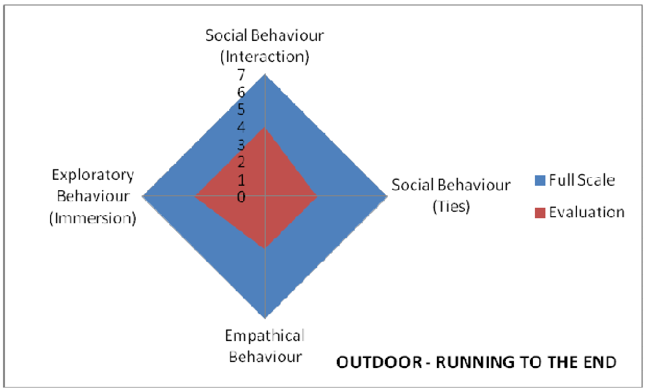

Figure 20: Outdoor joggers QoE - Running to the end

6.2.4 *Comparison of indoor HE vs indoor LE QoE*

If we compare only the indoor HE and LE experiences, interesting things appear to us. First of all, all the scores reported are higher in the LE configuration, as shown in the **Errore. L'origine riferimento non è stata trovata.**. In terms of *social behaviour* and *empathical behaviour*, results vary too much depending on users to identify a trend, but in terms of *realism* and *immersion*, we can identify that users utilizing the most immersive rendering device (theoretically with HE setup) reported a lower immersion and realism than users utilizing a simple screen. The only difference between those users was the point of view of the full body reconstruction. Indeed, indoor LE users see their own reconstruction whereas indoor HE see the full reconstruction of a remote player, and see themselves as an avatar.

This should be more investigated in a specific experiment, but we can draw the hypothesis than seeing our own reconstruction in an environment, teleport us in that environment and increase our feeling of immersion (see section 6.6.1).

In terms of *technology adoption*, no important differences between the two setups, but still a better adoption with simpler and lighter setup providing a better emotional behaviour after the experience to users.

Table 24: Comparison QoE - Indoor LE vs Indoor HE

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Performance Gain (Hedonic)	Exploratory Behaviour (Immersion)	Emotional Behaviour	Technology Adoption
Indoor LE	4.68	4.92	4.23	5.17	5.97	5.35	5.73	5.36
Indoor HE	3.94	4.3	3.62	3.82	4.73	4.2	4.93	4.27

6.2.5 *Comparison of indoor vs outdoor QoE*

If we compare the three setups of the 3D-LIVE platform deployed in Jogging LIVE3, one can see that the indoor user experience reported received higher scores than outdoors for most of the scores apart from *exploratory behaviour*. The feeling of immersion was reported higher by outdoor runners than indoor HE runners. We cannot really compare the outdoor and indoor setups in terms of immersion as the configuration is totally different, but these results show that outdoor runners feel they are running a race and that their position in the virtual world is consistent with the game. However their connection with other users was not as good as compared with indoors. Outdoor users reported lower *social* and *empathical* behaviours, which suggests that the only audio information is not sufficient to immerse users enough to make them interact much.

Generally, the *emotional behaviour* was quite high; people enjoyed the jogging platform and preferred it indoors than outdoors. The figures below show that the *technology adoption* reported was higher for indoor users in general, but acceptable for outdoor users as well, running a simple app.

Table 25: Comparison QoE - Indoor vs Outdoor

	Social Behaviour (Interaction)	Social Behaviour (Ties)	Empathical Behaviour	Performance Gains (Realism)	Performance Gain (Hedonic)	Exploratory Behaviour (Immersion)	Emotional Behaviour	Technology Adoption
Indoor LE	4.68	4.92	4.23	5.17	5.97	5.35	5.73	5.36
Indoor HE	3.94	4.3	3.62	3.82	4.73	4.2	4.93	4.27
Outdoor	3.53	3.18	2.6		3.9	4.4	3.75	4.03

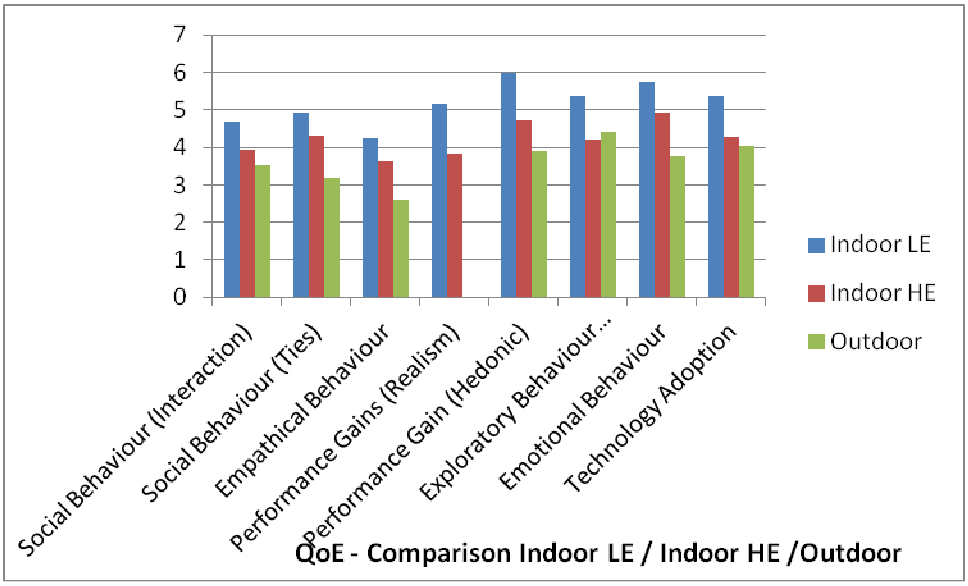

Figure 21: Summary of Jogging Live 3 QoE

6.2.6 *Summary of findings with respect to experimental objectives*

Based on this analysis, we can summarize our findings for the jogging use-case comparing the added value provided by our scenario elements as well as the platforms deployed. Here we outline the scenario elements, deployments and describe our main findings for tele-immersive jogging applications.

Indoor technical findings:

- Very good skeleton quality (>0.9)
- Good full body reconstruction quality and streaming rate (6fps remote site, 7.3fps local site)
- Application running smoothly
- Voice running without noticeable delays

Outdoor technical findings:

- Good frame rate
- GPS accuracy needs improvement: avatars path corrections required to provide consistent path.
- Voice service running well

Scenario Elements findings:

	Running as a group	**Running free to the end**
Indoor	- Good immersion for HE runners, far better for LE runners - Medium social interactions for HE runners, better interactions for LE runners - Medium realism for HE runners, Very good realism for LE runners - Similar empathical behaviours	- Similar scores. Immersion a bit lower for HE users while not running as a group anymore but Realism a bit higher. **Overall QoE:** Better for Low-End users than High-End Users.

	Overall QoE: Better for Low-End users than High-End Users; the main difference here was that LE users see their own reconstruction in the game while HE see the reconstruction of the remote indoor runner.	
Outdoor	- Lower scores in terms of Social Behaviour and Exploratory Behaviour **Overall QoE:** Good feeling of consistency of positioning in the shared world but poor immersion with remote users.	- Similar scores

Higher Quality of Immersion running as a group:

- Immersion seems a bit higher for the HE users while running as a group. No change for the LE users depending on scenario elements.

Higher Quality of Realism running free

- Realism is a bit higher for HE users while running free to the end. No correlation identified here

QoE: Better for LE users than HE users. The *social interactions* perceived as well as the realism and the feeling of immersion and engagement in the game were all reported higher by LE runners. The main difference is the representation of the user as a full reconstructed human instead of an avatar.

<u>Indoor application could:</u>

- Focus on *self-representation* of the user in the virtual environment
- Improve the *realism* of the virtual environment

<u>Outdoor application could:</u>

- Add an easy to access *feedback* of remote users (smart glasses)

To put it in a nutshell, technically the applications are running smoothly without stability issues. In terms of scenario, the experience is satisfying for indoor joggers but outdoor runners definitely miss a feedback of remote users.

6.3 Skiing

The skiing LIVE3 experimentation programme reported on two sets of experiments. One of these was the full LIVE3 deployment including users in Schladming and in Thessaloniki. In that experiment indoor skiers there were two variations of the setup: one using Full Body Reconstruction, and one using an Oculus Rift (described as HE version below). The second experiment was conducted in France and involved only a set of indoor users to compare the QoE of users running both the LE setup (using the Oculus Rift and Wii balance Board) and the HE setup (using a CAVE). During that experiment, a third indoor user was skiing from Greece to get a full body reconstructed player in the game, but his QoE was not observed.

6.3.1 *Summary of indoor LE QoE/QoS*

In the skiing LIVE3 experiments, the QoS measured for the indoor user focused more on the quality of his skeleton and his full body reconstruction. The results below show that we achieved good performance in the reconstruction of the moving humans and the streaming provided a mesh of a good quality (8.18 fps in the reconstruction, meaning 8 new meshes per second). At run-time we found that the compression frame rate falls moderately to 6.12 fps here meaning we lose some performance in the compression time required before sending the frames. After the compression the streaming framerate has been also changes the overall throughput as it is affected by network transmission delays. This final rate was more or less as expected given the overall capability of the system; the frame rate of the rendering of full body reconstruction in the receiving application was 4.6 fps. The skeleton quality reported by the capturer was very good as well, as the average confidence is 0.94 and the jerkiness is about 2.5mm.

Table 26: QoS data for indoor LE skiers

	QoS_Interactivity_Speed_Reconstruction Framerate	QoS_Interactivity_FrameRate full reconstruction rendered in Unity3D	QoS_Interactivity_Speed_Full Body Reconstruction Rate(reconstruction average compression ratio)	QoS_Interactivity_Speed_Full Body Reconstruction time (average reconstruction compression time)	QoS_Interactivity_Mapping_SkeletonConfidence	QoS_Interactivity_Mapping_Skeleton_quality	QoS_Interactivity_Mapping_SkeletonJerkX	QoS_Interactivity_Mapping_SkeletonJerkY
AV INLE	8.18	4.6	52.33	0.06	0.94	1488.31	2.39	2.34
MAX INLE	14.38	5.36	67.02	0.08	1	1901.52	3.26	3.65
MIN INLE	5.06	2.9	45.1	0.03	0.79	935.29	0	0
	QoS_Interactivity_Mapping_SkeletonJerkY	QoS_Interactivity_Mapping_SkeletonJerkZ	QoS_Interactivity_Mapping_Full Reconstruction RGB Sequence PSNR (Reconstruction vs Reference RGB Camera Sequence PSNR)	QoS_Interactivity_Mapping_Full Reconstruction RGB Instant PSNR (Reconstruction vs Reference RGB Camera Instantaneous PSNR)	QoS_Compressed Reconstruction vs Reference RGB Camera Sequence PSNR	QoS_Compressed Reconstruction vs Reference RGB Camera Instantaneous PSNR	QoS_Reconstruction Compression FrmeRate	QoS_Reconstruction Streaming FrameRate
AV INLE	2.34	2.65	14.63	14.313	14.26	14.16	6.12	4.913
MAX INLE	3.65	3.78	20.44	17.39	19.54	17.38	9.04	5.98
MIN INLE	0	0	0	0	0	0	4.43	3.41

6.3.2 *Summary of indoor HE QoE/QoS*

The indoor HE configuration reported fewer metrics, as the metrics regarding the quality of the full reconstruction were applicable only in the LE setup. In here we observed only the frame rate of the application, the frame rate of the rendering of full body reconstruction and the quality of the skeleton captured. In terms of frame rate of the application, we noticed that using the Oculus Rift here reduced the performance of the application and the frame rate was around 23fps in average. This is not as high as hoped, but can be easily optimized in the 3D environment or the computer chosen to render the application. Within the Oculus Rift, the rendering of the full reconstruction was achieved at 2.57fps on average; so here find there is a need to further optimise the last part of the rendering pipeline to ensure the final rendering rate is maximised. In this lower frame rate case, we might expect to see an impact on users' perception of the realism of remote users. Looking at the skeleton captured at this site, the values are still very good with an average confidence of 0.95 and jerkiness around 4mm.

Table 27: QoS Data for Indoor HE (Oculus Rift) skiers

	QoS_Interactivity_FrameRate of the XX App	QoS_Interactivity_FrameRate full reconstruction rendered in Unity3D	QoS_Interactivity_Mapping_SkeletonConfidence	QoS_Interactivity_Mapping_Skeleton_quality	QoS_Interactivity_Mapping_SkeletonJerkX	QoS_Interactivity_Mapping_SkeletonJerkY	QoS_Interactivity_Mapping_SkeletonJerkZ
AV INHE	22.77	2.57	0.95	3.71	3.75	3.47	4.08
MAX INHE	26.45	5.35	0.98	3.8	5.42	5.32	6.43
MIN INHE	18.82	0	0.92	3.62	2.08	2.34	2.3

Looking at the quality of experience, only the *social behaviour* was observed depending on scenario elements. However *exploratory*, *emotional* and *empathical* behaviour as well as *performance gains and technology adoption* were observed for the overall experience.

Looking at Social Behaviour

The scores reported for each scenario element, which were *at the meeting point*, *at the race starting point*, *during the race* and *at the end of the race*, were very similar in terms of *social interactions* and *ties*. Here we see that all the scores are high and varying around 5. The interesting bit here relates to one of our investigations: how will the users perceive the social interactions during the race? Actually LIVE2 experiments made us think that the race should be the moment where social interactions disappear. In LIVE3, users reported high values of *social interactions* and ties during this phase as well as during the other phases. This could mean that they *felt the ability* they had to interact even if they didn't actually interact significantly at the time, and do not lose the connectedness with remote skiers. This may be because the indoor sporting activity is easy and let users having usual interactions.

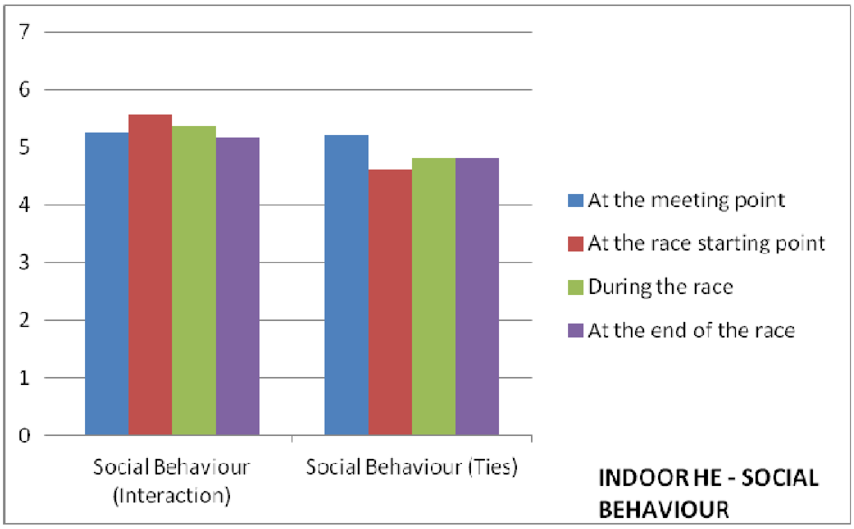

Figure 22: Indoor HE (Oculus Rift) Social Behaviour depending on scenario elements

Looking at the overall experience, one can see in Figure 22 that the QoE reported was very good.

Looking at Social Behaviour

The *social behaviour* score about the overall experience is 6.4. This value is very positive and let us think that indoor HE skiers felt very connected with remote skiers at different locations.

Looking at Emotional Behaviour

The emotional state of the indoor HE skiers after the experience is 4.83, which is good. The Head Mounted Displays like Oculus Rift can create sickness and discomfort; however it seems that users felt very positive after trying this 3D-LIVE setup.

Looking at Empathical Behaviour.

The *empathical behaviour* refers to the feeling to be encouraged, supported by remote skiers and reversely to be able to support and encourage them. The score reaches a value of 6.67. The value is very high and shows that users were fully engaged in the race.

Looking at Exploratory Behaviour

When consider the *exploratory behaviour* we look at the *focus* and *immersion* constructs. *Focus* refers to the easiness to control the activity of the player inside the virtual environment. Here the score reported was 4.4, which is acceptable but means it could be improved. For *immersion*, refering to feeling of being inside the virtual world, the capacity to have movements reproduced in the vritual environment and intreact inside it, reaches a score of 5.25. This values is very positive and shows the added value of the improvements made in terms of rendering and activity tracking.

Looking at the Performance Gains

The realism of the virtual environment, avatars and full reconstructed was evaluated through this QoE construct. Users reported an average score of 4.9. Skiers in Schladming were used to the slope and were able to understand easily where they were located on it, recognized the different landmarks. Overall they enjoyed the realism of the environment, the avatars and the full reconstructed humans. This score can be improved by the improvement of the 3D world, and the advances in the research about reconstruction of moving humans.

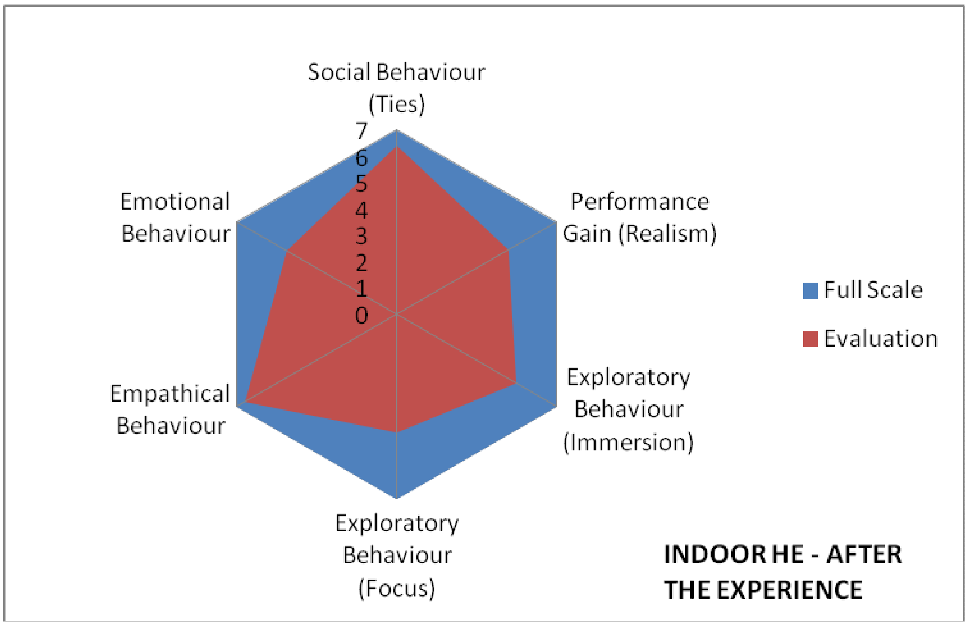

Figure 23: Overall QoE of indoor HE skiers

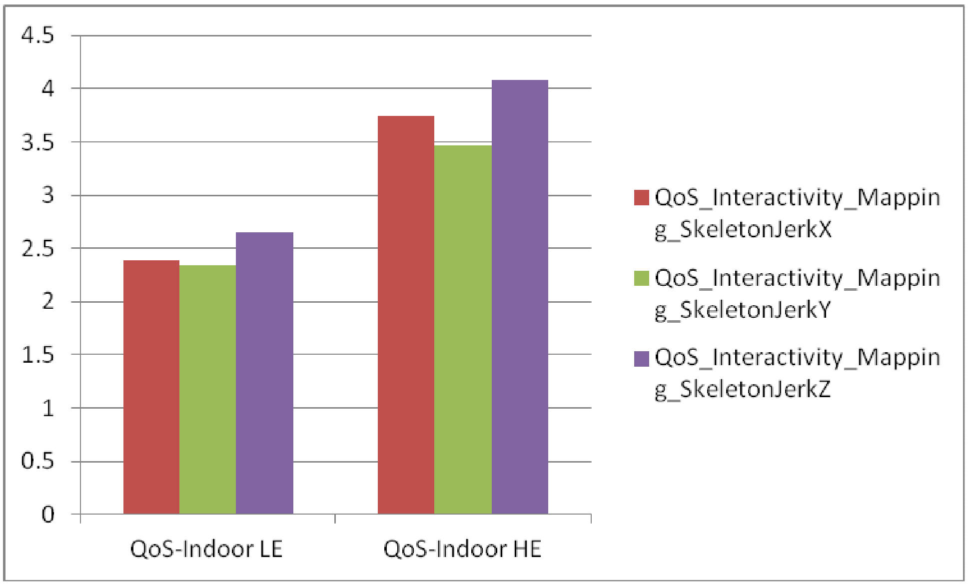

Figure 24: Skiing Skeleton Jerkiness Indoors

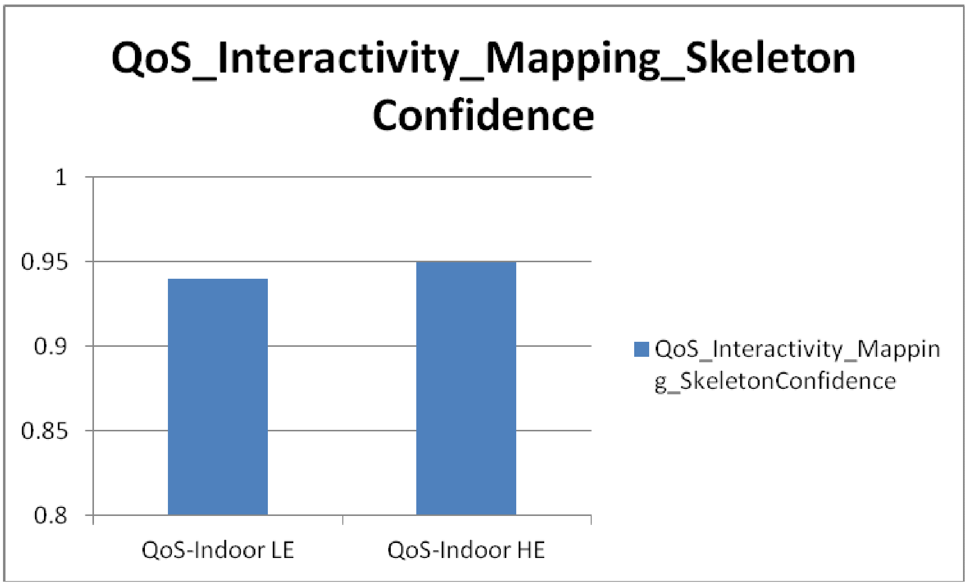

Figure 25: Skiing Skeleton Confidence Indoors

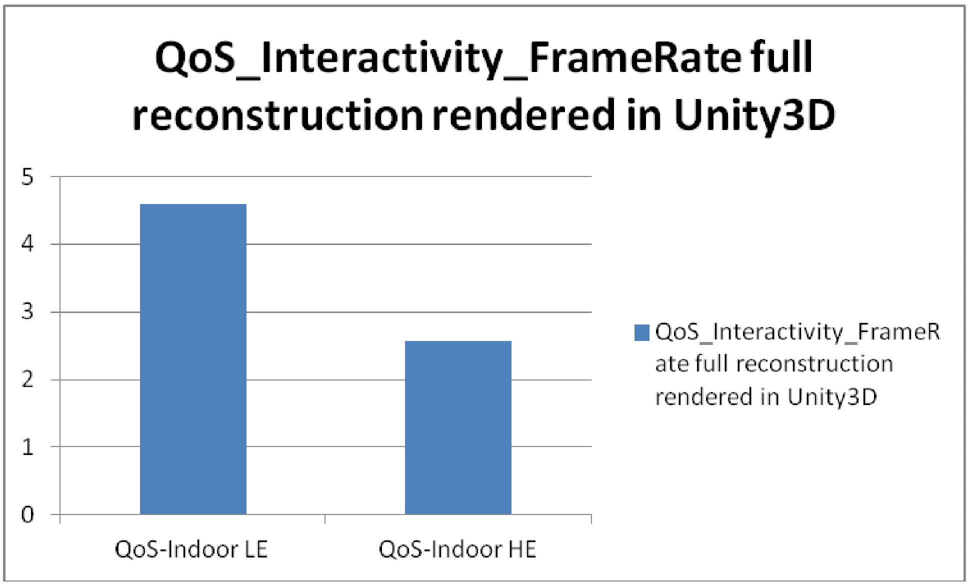

Figure 26: Reconstruction Framerate inside indoor client applications

6.3.3 *Summary of outdoor QoE/QoS*

A streamlined selection of metrics were observed on the outdoor client, focusing on performance of the application through the frame rate, and spatial consistency provided by the GPS of the Smartphone. The frame rate of the outdoor application (the software that drives the game logic and connectivity with other players) was very consistent and matched expectations in the final version of the prototype, varying between 30 and 60 fps with an average value of 39fps.

The GPS accuracy reported by the sensor inside the phone was around 7 meters and varied a lot depending on the position and speed of the skier on the slope. The value is higher than in LIVE 2; this must be due to the new slope topology driving to higher speeds and different satellites coverage. However the refresh rate measured was around 1.3 seconds, which allowed frequent updates in the positioning of the outdoor avatar on the slope and predictions in his trajectory.

Table 28: QoS of outdoor skiers

	QoS_Interactivity_FrameRate of the XX App	QoS_Vividness_SpatialConsistency_GPSAccuracy	QoS_Vividness_SpatialConsistency_GPSRefreshRate
AV OUT	39.12	6.95	1303
MAX OUT	64.52	10.07	1563
MIN OUT	30.84	4.31	995

Looking at the quality of experience, only the *social behaviour* was observed depending on scenario elements. However *emotional* and *empathical* behaviour; *performance gains* and *technology adoption* were observed for the overall experience of outdoor skiers.

Looking at Social Behaviour

Outdoor skiers reported scores similar to the indoor scores. Actually the only difference is about the race phase, where as we expected, the *interactions* and *ties* are lower. At the meeting point and the end of the race, users are represented as avatars in the mask. At the starting point and during the race, only pins represent the users. It seems that this did not really impact the *social behaviour* of outdoor users. We can see that during "static" phases, where the physical activity is limited (meeting, start and end of the race) outdoor skiers don't care about the way users are represented for social interactions and ties. However as we expected, during the "dynamic" phase which is the race, the social interactions and ties decrease. What we did not expect is such a high value of social behaviour during the race: indeed 4.42 for interactions and 4.33 for ties; this seems still high during a phase which is not appropriate for social interactions: skiers are hurtling down the slope at high speeds and cannot interact much at the same time. So the good news for the platform here is that skiers still feel connected even if they do not socially interact much during the race.

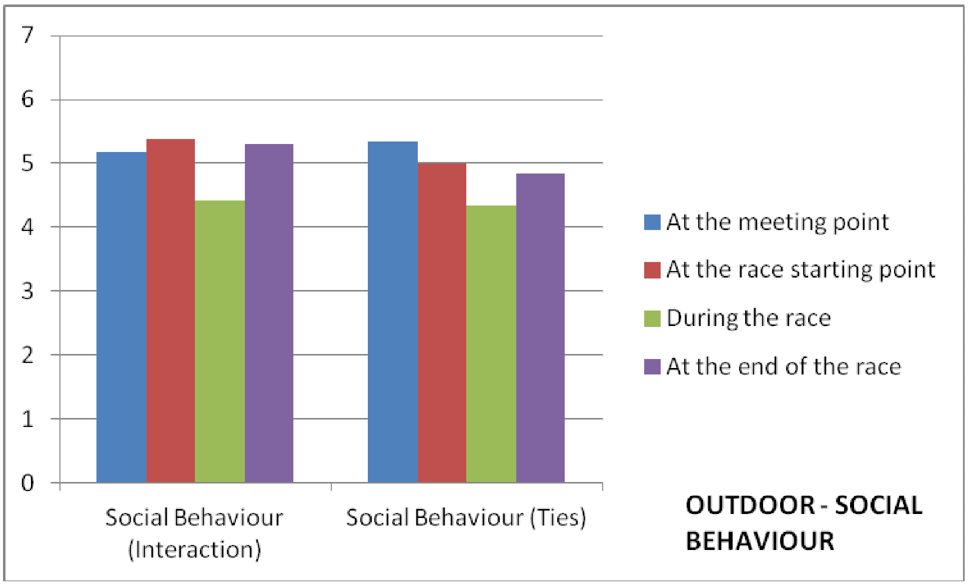

Figure 27: Outdoor Social Behaviour depending on scenario elements

The figure below shows the overall QoE of outdoor skiers reported after their experience – here the values are good; *performance gains* shows a medium score.

Looking at the Social Behaviour

The *ties* reported by the outdoor skiers after their 3DLIVE ski experience reach a score of 5.75, which is very high compared to past experiments. Outdoor skiers reported a good feeling of connection with remote skiers during the overall experience.

Looking at the Empathical Behaviour

Empathical behaviour receives a score of 4.4 in average by outdoor skiers, referring to the sense of encouragement and engagement in the game with other players. Such a value confirms that for this kind of scenarios, where social interactions are made difficult during the main activity decreases the engagement with remote users but keep skiers focusing on their actual main activity.

Looking at the Performance Gains

The realism reported by outdoor skiers got a medium value of 3.6. Actually the realism inside the mask application was not our target due to hardware constraints, but this medium value depicts a good appreciation of the rendering of avatars and mountains inside the Recon Snow2 Head-Up Display. Realism could certainly be improved, but it was acceptable in LIVE 3 prototype.

Looking at the Emotional Behaviour

The score of the *emotional behaviour*, representing the state of outdoor users' frame of mind after the experiments, is 5.33. Outdoor skiers really enjoyed the 3D-LIVE outdoor configuration, as they were pleased, surprised and challenged by this mixed reality setup.

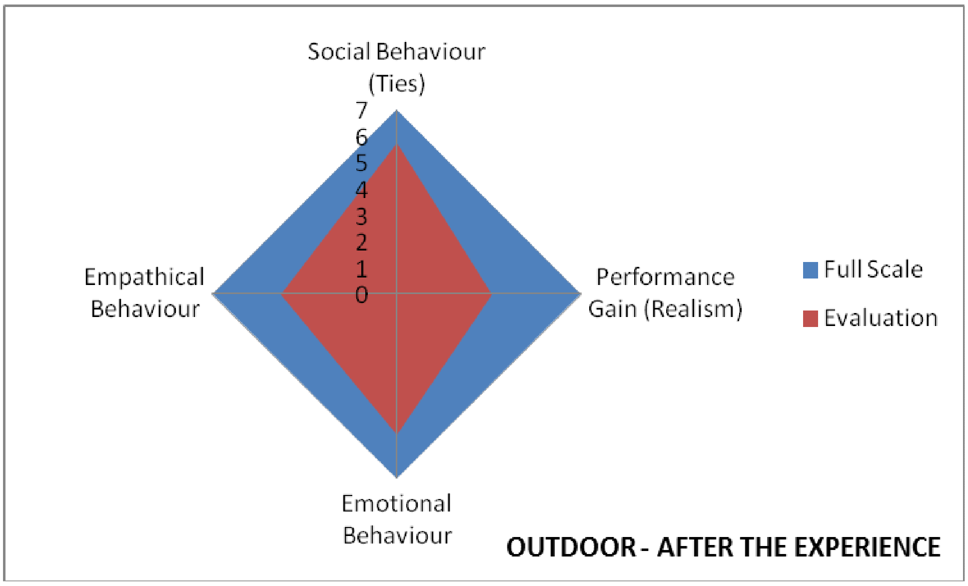

Figure 28: Overall QoE of outdoor skiers

6.3.1 *Comparison of indoor vs outdoor QoE*

In the 3D-LIVE skiing LIVE 3 experiments, both indoor and outdoor deployments generated high scores in the evaluation of quality of experience. If we compare the overall results in terms of QoE for indoor HE and outdoor skiers in Schladming, the results are very interesting and summarize what we identified in the previous sections.

The *social behaviour* evaluated got the same scores around 5 in both configurations. It does seems that it may not matter too much if the user is indoors or outdoors, the interactions are shown to be consistent in both cases. The only light difference is explained by the race phase where outdoor skiers cannot easily talk while skiing fast, thought they remain strongly connected to the others.

The *performance gains* (realism) of the virtual scene and the avatars is lower in the outdoor application. This is what we expected as the outdoor application displays a simplified scene compared to the indoor application and only avatars to represent indoor players. Since the outdoor player did not themselves in the virtual scene, we were not able to ask detailed questions relating to their sense of immersion (part of the *exploratory behaviour* construct) in a virtual environment since their point of view is always rooted in the real world. Consequently skiers reported a lower realism in this configuration, with still an acceptable value. The *performance gains* (Hedonic) reported is very high in both configurations with similar scores (6.63 indoors and 6.39 outdoors). Skiers had much fun and enjoyed the race in the simulator and on the real slope though the experience is totally different.

The *emotional behaviour*, reporting the users' state of mind at the end of the experience, reported higher values in the outdoor configuration than the indoor, with high scores in both (4.83 indoors and 5.33 outdoors). The outdoor application seems to generate more pleasure and satisfaction to skiers than the indoor application, perhaps thanks to the skiing activity itself.

Empathical behaviour is the only construct for which values are really different between outdoor and indoor skiers. Looking at the different scenario elements, this seems correlated to the fact that the race phase does not allow outdoor skiers to focus on remote users' interactions due to a hard physical activity.

Seeing the different scores presenting the user experience of both outdoor and indoor users, the final construct was about the *technology adoption* of the users - the 3D-LIVE platform gets high scores here. Users think this kind system is useful for gaming and sporting purposes, and that it is almost ready for a deployment. The scores of *technology adoption* were in average 5.63 for indoor users, and 5.22 for outdoor users. If a platform like 3D-LIVE is designed for skiing applications, it may meet a highly motivated audience.

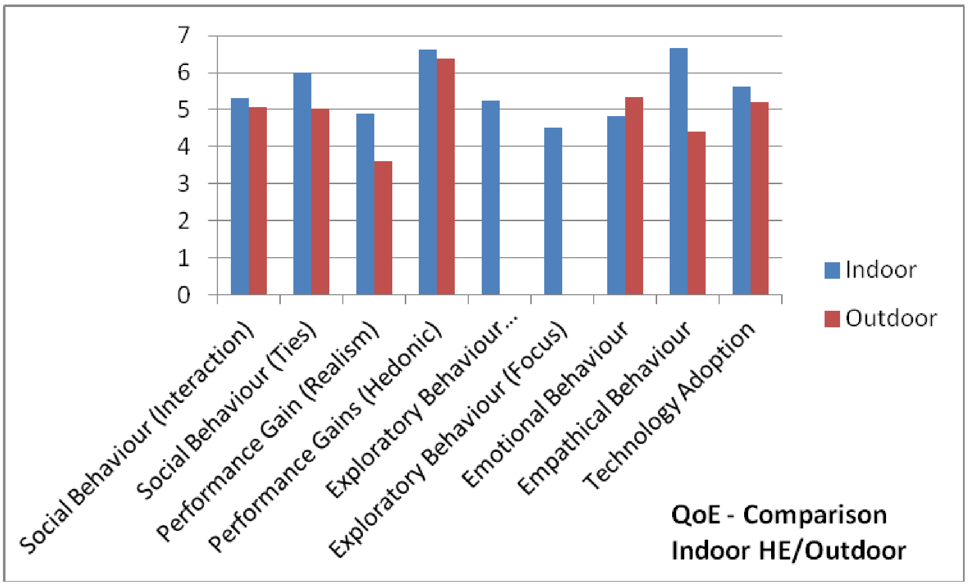

Figure 29: Overall QoE of outdoor skiers

6.4 Summary of findings with respect to experimental objectives

Based on this analysis, we can summarize our findings for the skiing use-case comparing the added value provided by our scenario elements as well as the setups deployed. For each of the scenario elements and setups we will list our main findings and recommendations for tele-immersive skiing applications.

<u>Indoor technical findings:</u>

- Very good skeleton quality, providing good sense of being in the virtual world.
- Frame rate sometimes limited due to Oculus Rift integration, which could disturb user experience in some areas, so rendering optimization is suggested.
- Lower values in reconstruction rendering frame rate which may impact perceptions of performance gains could also benefit from optimization.

<u>Outdoor technical findings:</u>

- Frame rate very good for outdoor application
- GPS accuracy: 7m due to high speeds. Constrain to trajectory correction and prediction algorithms mitigated this; a refresh rate of 1.3s to feed this algorithm was used.
- No more voice delays, communications clear between users.

Scenario Elements findings:

	All phases	**After the Experience**
Indoor	- Very good social behaviour perceived for all the scenario elements.	- Users reported a very good Quality of their Experience in all the dimensions observed. We can see that the empathical behaviour and social behaviour were specifically high. - The Emotional Behaviour could be improved, Oculus Rift might have disturbed some skiers after several minutes of use - Focus, corresponding to the naturalness of the control of the skier could be improved as well.
Outdoor	**Social Behaviour a bit lower during race phases:** As expected, outdoor user must focus on his activity during the race. The interesting score: even if he does not interact, the scores are high and the skiers feel connected.	- Need to improve the Realism in the Head's up display perceived by users. - Very good Ties and sense of connectedness with other users. - Very good emotional behaviour after this outdoor experience.

Indoor findings:

- The overall QoE seems better with an Oculus Rift rather than a CAVE setup.

Outdoor findings:

- The HUD view is very immersive for outdoor users who still feel connected during a race even when they do not socially interact.

Indoor application could:

- **Improve the graphics** and the **control for** the skier

Outdoor application could:

- **Improve the graphics** inside the HUD and investigate further ways to enhance engagement with users together during the race. Consider using AR checkpoints or mini games on the slope.

To put it in a nutshell, technically the indoor application could be optimized as the Oculus Rift integration takes much more resources. The outdoor application runs very well and we should explore the limitations of the HUD, to improve the graphics inside. In terms of scenario, skier really enjoyed the experience inside and outside, the application displays to the skiers what they need at the appropriate time Indoor skiers might prefer an Oculus Rift deployment rather than a CAVE deployment.

6.4.1 *Comparison of indoor deployments QoE out of LIVE 3*

In addition to the main LIVE3 skiing experimentation, an additional session was executed in France to compare the impact of two indoor deployments: a very high-end prototype including a pro ski simulator, and a version with a Wii Fit board and an Oculus Rift. The application running was the same and a third indoor user joined the game from Greece with his body fully reconstructed in the game.

The same questionnaires used for the main LIVE3 trial were distributed to the users in France, whom were randomly selected to try the two configurations. Twelve users experimented the system, including VR experts and novices, four females and height males aged from 26 to 50.

Results are presented below, where in fFigure 30 we see the aggregated QoE depending on each scenario element. Scores in this figure mix the different dimensions and summarize the overall QoE score. The values are quite high and similar to the scores obtained in LIVE3 ski experiments. The interesting point here is that the best QoE has been obtained for the OculusRift+WiiFitBoard version, which is a simpler version compared to the very High-End deployment CAVE+ProSkiSimulator.

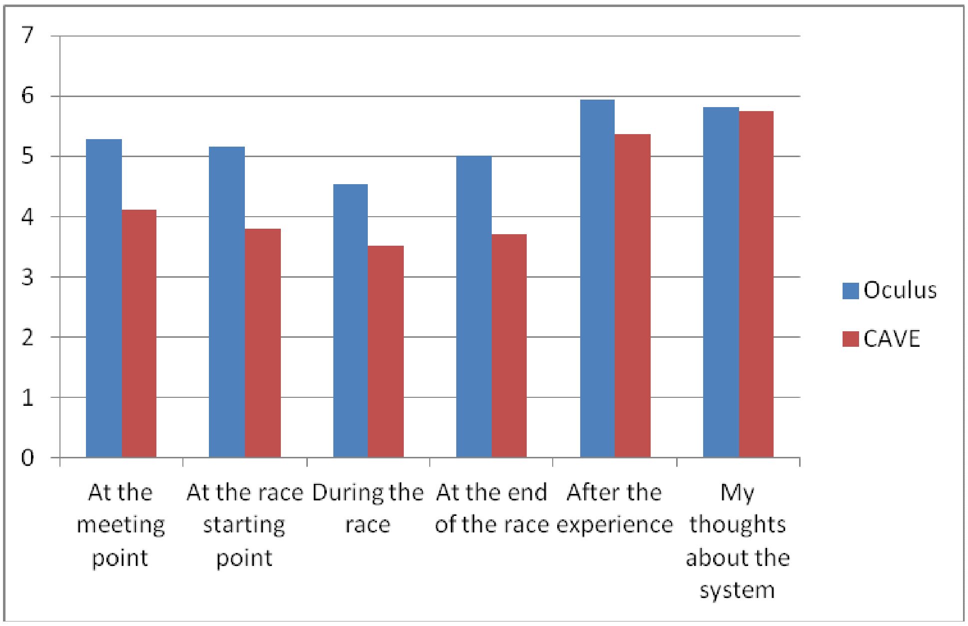

Figure 30: Comparison overall QoE between indoor users using CAVE+ProSkiSimulator / OculusRift+WiiFitBoard

We tried to identify the overall quality of experience by dimension instead scenario element; this is summarized in the results in the figure below. The Oculus Rift version got again better evaluations on almost all the dimensions. The only dimension the CAVE version reported a better score is the *exploratory behaviour: immersion*.

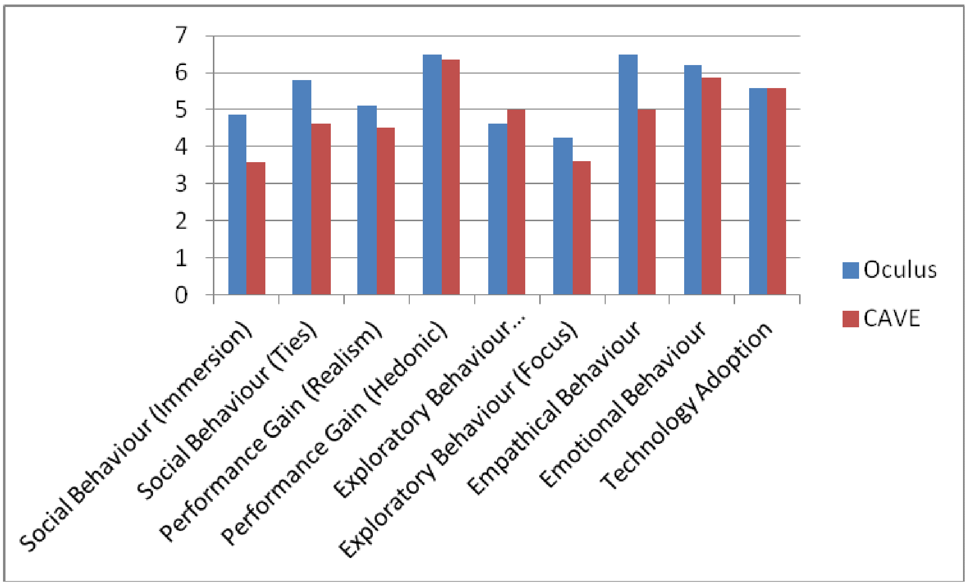

Figure 31: Comparison overall QoE by scenario elemetns between indoor users using CAVE+ProSkiSimulator/OculusRift+WiiFitBoard

6.5 Comparison of LIVE 3 with LIVE 2

Comparison of Quality of Experience between LIVE2 and LIVE3 can lead us to interesting thoughts. In reviewing the Golfing QoE profiles, it seems that golfers evaluated slightly better *social behaviour* and *performance gains* in LIVE2, whereas a better *exploratory behaviour* and *emotional behaviour* were reported in LIVE3. Between LIVE2 and LIVE3 the technical work carried out concerned mainly the robustness of the activity recognition features (expecting an impact on *exploratory behaviour*: *focus*) and the scenario itself, splitting the game into more phases to better understand the score and the status of each player (here anticipating an impact on the overall *emotional behaviour*). It seems that we succeeded in increasing both *exploratory* and *emotional behaviour* of golfers.

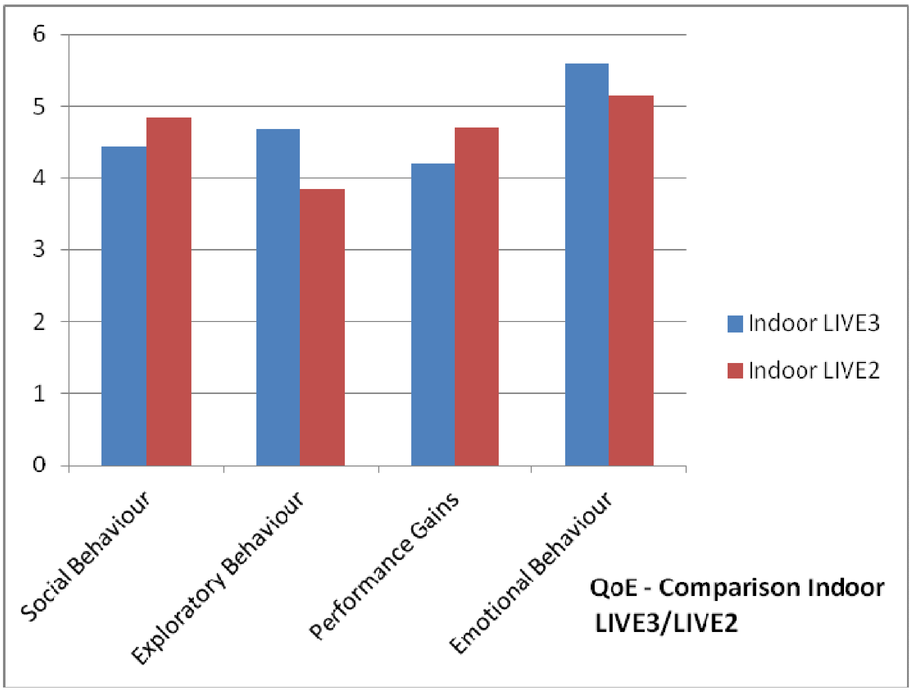

Figure 32: Comparison LIVE2/LIVE3 QoE for Indoor Golfers

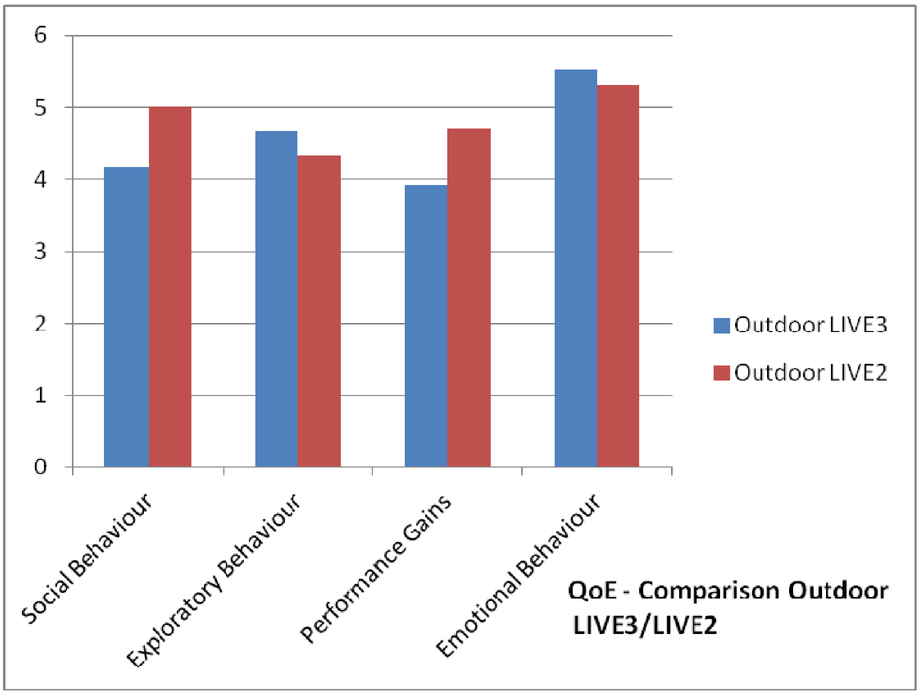

Figure 33: Comparison LIVE2/LIVE3 QoE for Outdoor Golfers

If we observe the results for the Skiing scenario, we cannot compare outdoor experience as only a few outdoor users participated in LIVE2 outdoor trials. However, we can instead compare the overall experience of indoor skiers. In this case, the results are positive as we can see in the figure below. For most of the dimensions evaluated, a significant improvement has been reported thanks to the numerous technical and conceptual improvements made on the platform. The most impressive score is noted for the *empathical behaviour*: in LIVE3 this dimension got 2.5 points more than in LIVE2. The only dimension that did receive a lower score in LIVE3 is the *emotional behaviour*. This dimension actually reports the state of mind of skiers after the experience, and this time indoor skiers were wearing an Oculus Rift, which can lead to cyber sickness; this could be one of the reasons for the lower score in LIVE3.

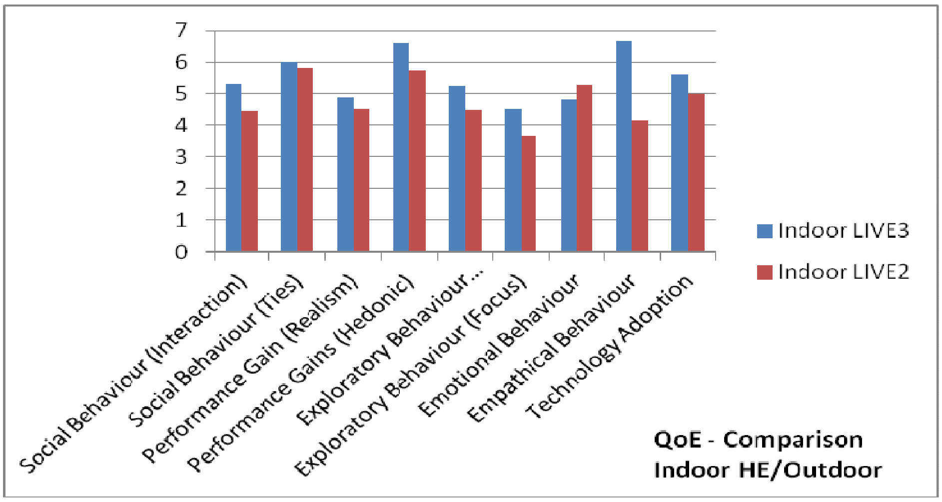

Figure 34: Comparison LIVE2/LIVE3 QoE for indoor skiers

Studying the different reported QoE scores from the Jogging evaluations, we can see that the results are varying depending on the configurations. For the LE indoor users, the experience seems quite similar in LIVE2 and LIVE3 with some positive variations for most of the dimensions. User perceptions of realism and technology adoption were slightly higher in LIVE2 but no significant technical changes to rendering or physical hardware in the final jogging prototype to potentially account for this change in attitude.

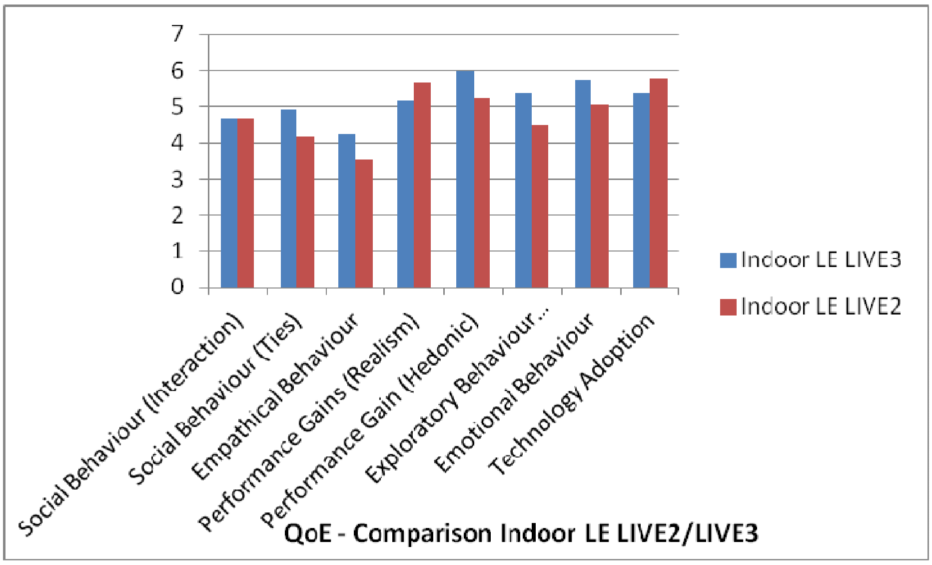

Figure 35: Comparison LIVE2/LIVE3 QoE for indoor Low-End Joggers

For the HE indoor users the same is not true - two dimensions have better scores in LIVE3: the *empathical behaviour* and the *exploratory behaviour*. This change can be linked at least in part to the enhancements made to the activity recognition and speed estimation of indoor runners between LIVE2 and LIVE3. However the other dimensions received a better evaluation in LIVE2. The constructs *ties*, *hedonic gains* and *technology adoptions* were reported higher in LIVE2.

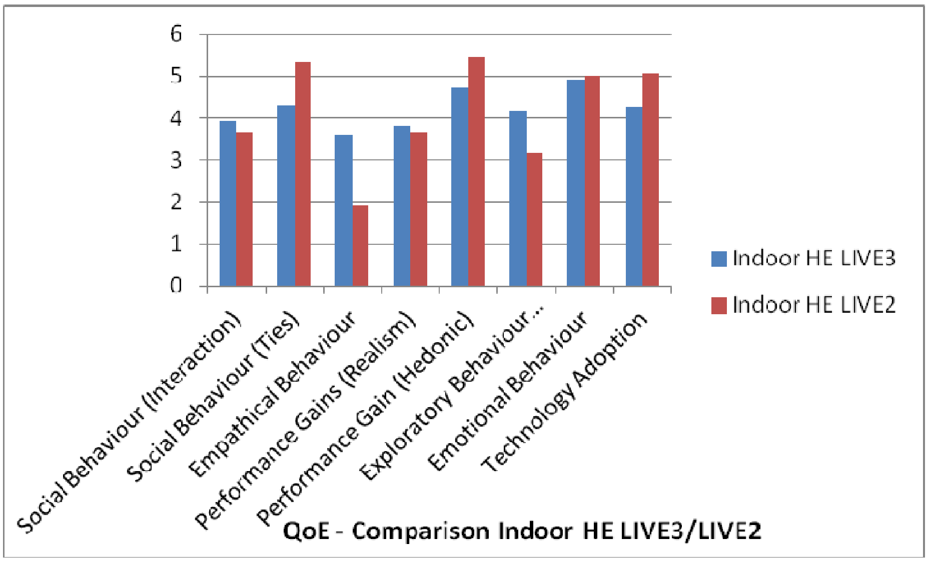

Figure 36: Comparison LIVE2/LIVE3 QoE for indoor High-End Joggers

Studying the results in LIVE2 and LIVE3 for outdoor runners, we can see that the results are similar but for the *exploratory behaviour* and *emotional behaviour*. The immersion reported was 2.5 points higher in the LIVE3, which is a very positive evaluation, however the emotional state of outdoor joggers at the end of the run was 1.2 points lower in LIVE3. Perhaps users who already knew the concept felt immersed easier in the race and get engaged in the new scenario instructions, but finally got disappointed by the lack of new features between LIVE2 and LIVE3.

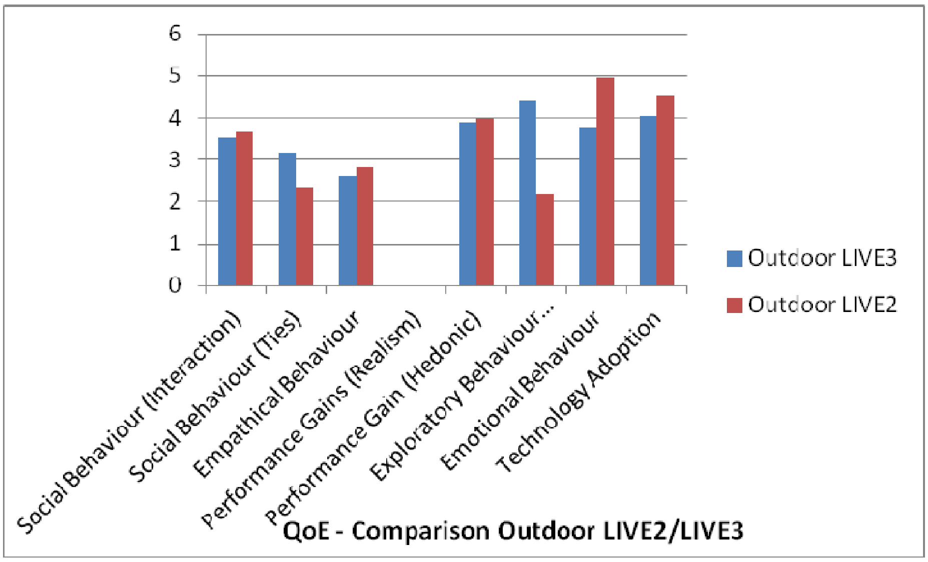

Figure 37: Comparison LIVE2/LIVE3 QoE for Outdoor Joggers

6.6 Heuristics for mixed reality system design

Through this (and the previous) experimental phase of the project we have learned a great deal that relates specifically to the provision of a tele-immersive experience for golfing, jogging and skiing scenarios – as they were imagined and implemented. Whilst we note that the particular scenarios, technologies and experiments examined in this project may have many special characteristics that are not readily generalizable, it was possible to identify a number of interesting factors from the qualitative (and some quantitative) data that offer support for the definition of heuristic rules to guide TI design and development practice in the future. In order to formulate these heuristics, we first aggregated significant experimental evidence (from LIVE3 and also LIVE2) that aligned with the 3D-LIVE UX model (as described in the analysis sub-sections above).

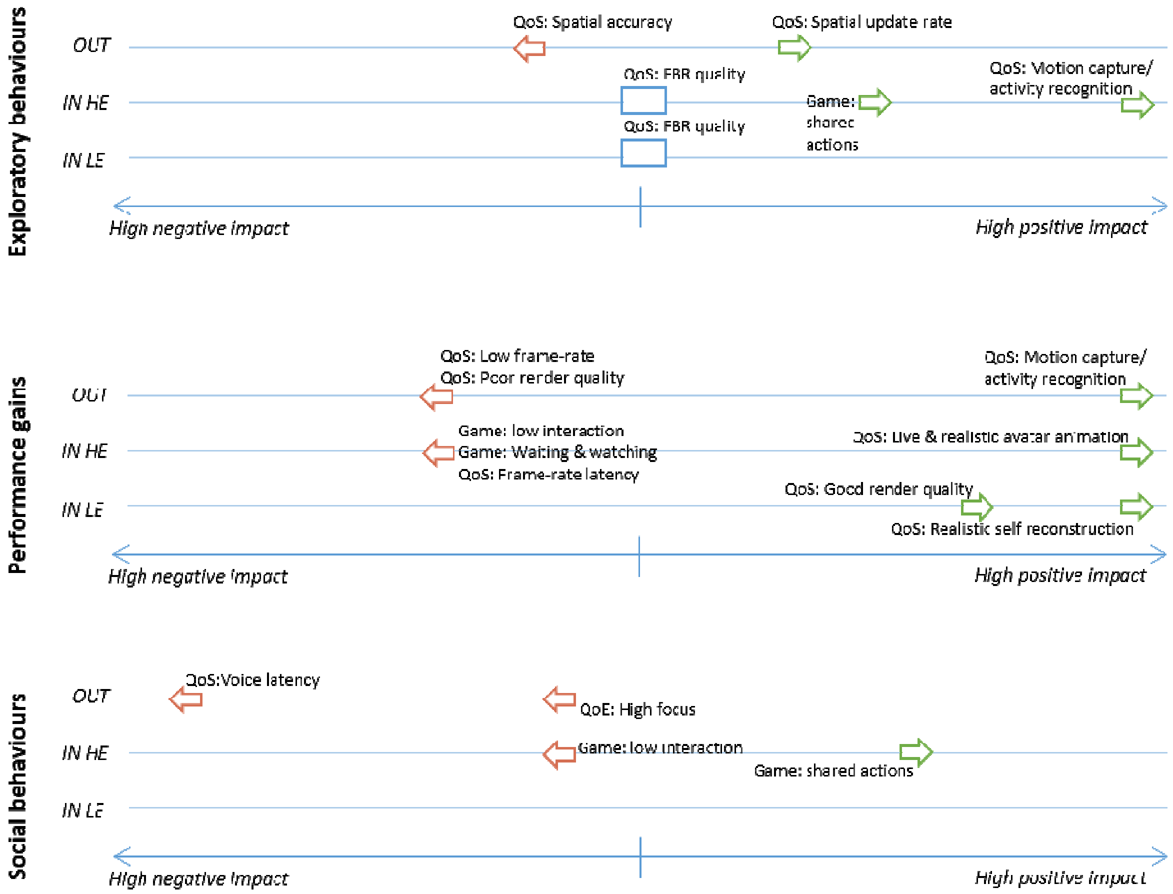

Figure 38: Impacts on UX in a TI environment

In the figure above we visualise those factors that we discovered to impact UX constructs *exploratory behaviours*, *performance gains*, and *social behaviours* either positively or negatively. Evidence for the other UX constructs (*empathic* and *emotional behaviours*; and also *technology adoption*) were also sought, but we found that the user responses in these cases were difficult to differentiate or correlate to a specific 3D-LIVE component, QoS metric, or platform configuration since they often either converged to median or were uniformly quite high. For this reason, we suggest that the main influential constructs that most significantly characterise user experience in a mixed reality, tele-immersive environment like 3D-LIVE are formed of these principal UX model constructs:

- Exploratory behaviours

  - Level of immersion
  - Level of focus
- Performance gains
  - Hedonic experience (pleasure/challenge/motivation)
  - Ergonomics (level of realism/clearness)
- Social behaviours
  - Degree of interaction (with others)
  - Level of ties (with others)

Summary of impacts for exploratory behaviours

Exploratory behaviours broadly suggest the level of immersion our users felt during game play. We show in Figure 38 that the most significant factors we have found that influence these feelings relate to the physical behaviours and context of users. Timely and high quality motion capture and activity recognition are important here as it binds user's bodily behaviour with actions and events in the virtual world. This factor is also linked with ensuring that the game design includes meaningful and significant actions that are `shared' between users (i.e., events such as taking a golf shot or passing a skiing competitor). Here we proposed that high quality, meaningful actions that can be shared between users enhances their sense of immersion. Also related to this function of immersion is the degree to which accurate spatial positioning (provided by GPS data) impacts game-play. This data provides overall positioning of the user within the environment and the current 3D-LIVE implementation has been shown to be sufficient to maintain consistent game play when the update rate is high enough to support error correction adequately (however, poor resolution GPS data can negatively impact UX in small areas, such as on the golfing green). Finally, we find that variance of full body reconstruction data quality did not have a significant impact either way on exploratory behaviour during game play; changes in image quality of a remote user by another were not noticeable here. We note here that overall frame-rate for the reconstruction process is relatively low – due to the high computational demands; the performance related to the compression and transmission of this data is discussed further in section 7).

Summary of impacts for performance gains

High quality motion capture, activity recognition and avatar animation also plays a very important role in user's perception of their individual *performance gains*. This aspect of UX characterises their engagement with the challenges of the game and the implicit pleasure of realising their achievements through a clear understanding of their actions in a realistic environment. Here we argue that timely and accurate avatar animation positively reinforces users' perceptions of their influence in a virtual environment towards a personal goal. Visual realism appears to play a significant role in the mapping between the real and virtual for low-end (LE) users who do not benefit from a display that effectively encloses them in virtual world. Here the realistic rendering of the environment and, in particular, of *themselves* seems to contribute positively to their user experience. Conversely, aspects of system performance that degrade rendering quality (such as a poor frame rate or low levels of realism) can acts to reduce user ratings here. Similarly, from a game design point of view, user's sense of challenge and motivation will be reduced where periods of interaction levels (waiting and watching) are introduced.

Summary of impacts for social behaviours

Social behaviours represent those aspects of a shared experience which are determined by communicative interactions that reinforce the sense of belonging to a group. From the perspective of promoting social behaviours within the TI user group, a balance must be struck in game design between designing too many phases where interaction is either too low and or too high. In the former case, periods of low levels of interaction provide no notable events that can be discussed; in the later, where game interactions demand a very high level of focus and concentration there is often no resource left for the user to engage socially with others. Therefore a carefully designed game format that supports opportunities for social interaction and reflection of game events is important – and must be maintained by a good quality audio channel: the effect of latency or noise in this case is strongly negative.

UX driven heuristics derived from the 3D-LIVE project

With these observations in mind, we present a logical model that integrates UX inputs (combined to result in an immersive experience in a shared TI environment) with important game design constructs and supporting QoS goals; see below.

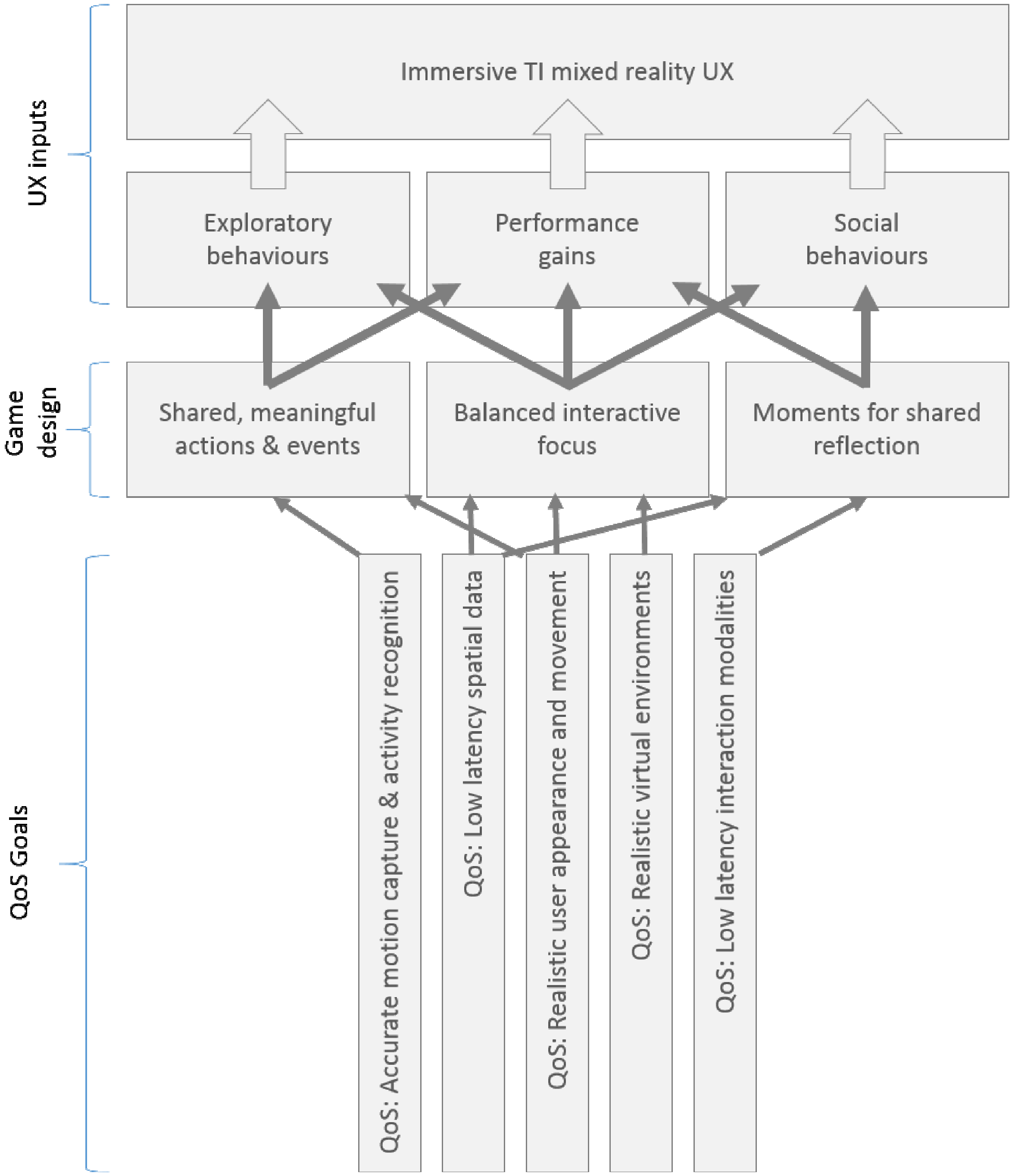

Figure 39: 3D-LIVE TI mixed reality UX model

In this model we see how the three primary UX components are supported by game design level foci; these in turn are realised by QoS goals that should be realised by the underpinning technology. From this we offer the following heuristics:

TI design heuristics

Elicit meaningful actions and events from your domain experts and users early. Deriving actions and events that are immediately recognisable and usually co-experienced in the real-world are important anchors for capturing user engagement in terms of immersive actions (which are also meaning to others).

Design your TI scenarios such that users are able to balance their focal attention on interaction with the ability to compare their actions with others. Providing the right level of balance interactive focus, that includes an effective mapping of human actions to meaningful virtual actions, allows users to focus on the challenges and personal accomplishments of the game.

Provide moments for shared reflection. Users should be provided time in the game where they can communicate their experiences (meaningful actions; performance) with others. This communication should be supported by both the ability to share consistent spatial co-location with natural moments in the activity where social interaction can be allowed to flow.

TI QoS heuristics

Provide the best motion capture and activity recognition possible. Here you should optimise and prioritise the related QoS such that it most accurately supports those actions and events in the game design that have the most meaning and impact to users.

Provide rapid updates for spatial data. Highly accurate positioning data from GPS sources is not always possible; the effects of this error can be mitigated somewhat by maximising sampling rate and providing error correction where possible.

Aim for a high level of visual realism. Especially for users that do not interact within an 'encompassing' visual display such as a CAVE environment or head-up display, providing a realistic graphical environment and portrayal of themselves is important.

Keep latency down. In particular, we stress the need to maintain a continuous audio stream between users so that moments of reflection can be shared without disrupting UX. There may be occasions when this audio QoS could be sacrificed (to some degree) for higher levels of visual consistency during parts of a TI scenario where both user focus and physical interaction is high.

6.6.1 *Future experimental hypotheses*

For further research work in immersive and tele-immersive platforms we propose a list of hypothesis to experimentally investigate on further user groups within more controlled environments in order to provide further evidence to support the 3D-LIVE findings:

- *Perceived tele-immersion is higher when users are performing an activity rather than observing the activity of remote player.*
- *Perceived tele-immersion is higher when users see their own reconstruction instead of an avatar in the virtual environment.*
- *Perceived tele-immersion is higher when users observe their reconstruction presented in 1st person instead of 3rd person view.*
- *Perceived tele-immersion while users see their own reconstruction is significantly impacted by the frame-rate of full body reconstruction.*
- *Perceptions of the presence of other users is higher in a CAVE environment than compared to wearing a HUD device.*
- *When using a HUD display, perceptions of user presence is higher when users are rendered using full body reconstruction rather than conventional avatar presentations.*

7 Network Adaptation Service experimentation

In addition to the LIVE 3 user trials conducted at the selected scenario venues, a series of experiments supporting the design and evaluation of the Network Adaptation Service (NAS) developed as part of T3.6. Due in part to the necessity of some of the experimental investigation (which forms part of the design basis for the NAS and needed much more controlled experimental conditions) and also due to project resource and timing constraints, these experiments were conducted outside of the scope of the LIVE 3 user trials. Instead, the experiments were focussed purely on the impact of network related QoS factors on the delivery of full body reconstruction data and the ability of the NAS to provide adaptive behaviour to optimise performance of the 3D reconstruction at run-time.

Details relating to the architecture and implementation of the NAS are described in deliverable D3.3; here we briefly revisit the 3D reconstruction pipeline and then go on to specify the experimental process taken to understand the factors that impact the throughput of full body 3D reconstruction frames in a distributed, networked environment.

Our approach to developing the NAS was a synthesis of model-based and empirical methods. These were comprised of three main phases: i) experimentation under laboratory based, controlled experiments to define pipeline performance characteristics, ii) design and implementation of an adaptive compression process; and ii) `real-world network' experimental evaluation of the adaptive process using a sub-set of the 3D-LIVE platform updated to include real-time adaptive mesh compression.

7.1 Phase 1: Pipeline performance modelling

In the first phase, our objectives were to determine the performance characteristics of the TI pipeline in a controlled environment so that an adaptive algorithm could be defined based on observable traits of the system process. We began by developing an abstracted view of the reconstruction pipeline, in its simplest form (i.e., one sender of reconstructed 3D data to one receiver); this is composed of two 'local' phases and an intermediate network transmission phase, see Figure 40. In the first local phase, vector λ1 represents a frame inter-arrival time (an aggregate of the time required for multi Kinect data sets to be captured and then fused into a single 3D model). The integrated 3D model is then compressed (adaptively using the NAS) at node µ1 before entering the network transmission phase.

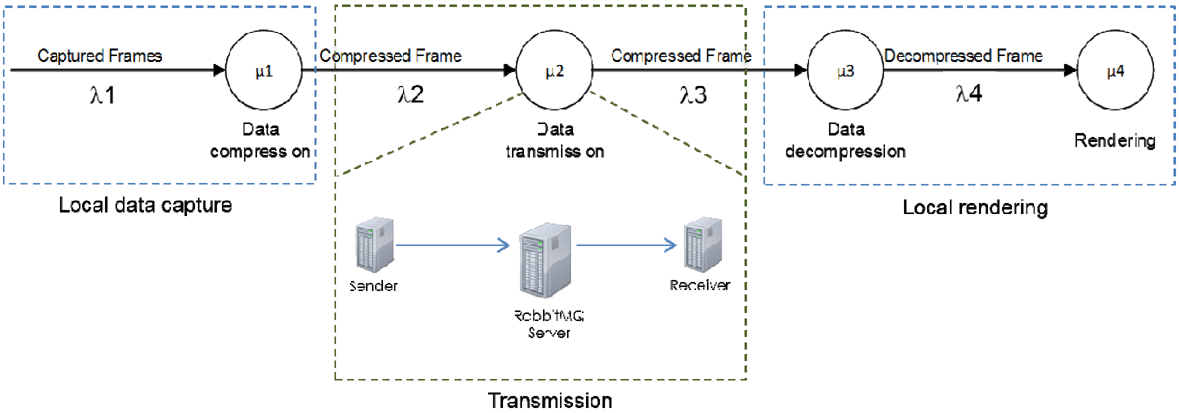

Figure 40: Full body reconstruction abstract pipeline

Transmission across the network is approximated by two network data carrying steps λ2 and λ3 and a data distribution processing operation carried out on a message brokering server (RabbitMQ in this case) during which 3D frame data is routed to the appropriate target. Finally, phase three represents the reception of the data by the machine that renders the 3D mesh to the end user (nodes μ3 and μ4). The process outlined above provided us with a conceptual foundation upon which to develop an adaptive method to respond to varying network conditions.

Performance of in-memory processes of the pipeline was addressed first: nodes λ1, μ1, μ3, λ4 and μ4 were approximated using normal distributions captured from empirical observations of 3D frame data throughput on `sender' and `receiver' machines. In order to constrain the problem space, we defined three levels of 3D reconstruction quality (with an inversely correlated compression level) that would be applied at the compression step (see table below).

Table 29: Full body reconstruction quality levels

Quality level	Average bytes/frame	Std. dev bytes/frame
High	244391.52	17013.72
Medium	192811.64	15219.44
Low	163358.56	17013.72

Frame inter-arrival rate (λ1), representing the arrival of a `raw' 3D frame (and therefore not compressed to a certain quality level) was benchmarked at an average rate of 155.3ms per frame. Message brokering process time was modelled in a similar fashion by passing pre-recorded 3D data frames through the RabbitMQ server operating on a local machine and calculating the normal delay distribution. A summary of the in-process benchmarks for these components of the pipeline are summarized in the table below, showing performance measures for corresponding 3D frame quality.

Table 30: Full body reconstruction pipeline constants

Pipeline node	High quality	Medium quality	Low quality
µ1 average (ms)	91.77	91.62	91.48
µ2 average (ms)	1.6198	1.4994	1.4294
µ3 average (ms)	30.77	28.56	28.8
µ4 average (ms)	33.3	33.3	33.3

Our results show that the in-memory performance characteristics for 3D frame data carried at our pre-defined quality levels can be treated as an effective constant within the pipeline model.

7.2 Phase 2: BonFIRE emulation experimentation

Transmission time modelling required an infrastructure that would allow experimenters to control the performance characteristics of a physical network. In this case, we used the BonFIRE experimental facility[1] to replicate the TI pipeline described above. BonFIRE

[1] http://www.bonfire-project.eu/

provides experimenters control over a number of different configurable parameters including latency; bandwidth; packet loss and router queue size. The large number of possible experimental permutations (given variable 3D frame data sizes and potential network conditions) required us to reduce our initial problem space by selecting two primary variables experimental variables to manipulate: network bandwidth and latency.

Table 31: BonFIRE experimental levels

Level	Bandwidth (Mbps)	Latency (ms)
High	100	40
Medium	60	25
Low	20	15

A series of experiments were then conducted in which we manipulated network bandwidth and latency conditions whilst sending 3D frame data through the pipeline at either *low*, *medium* or *high* quality levels.

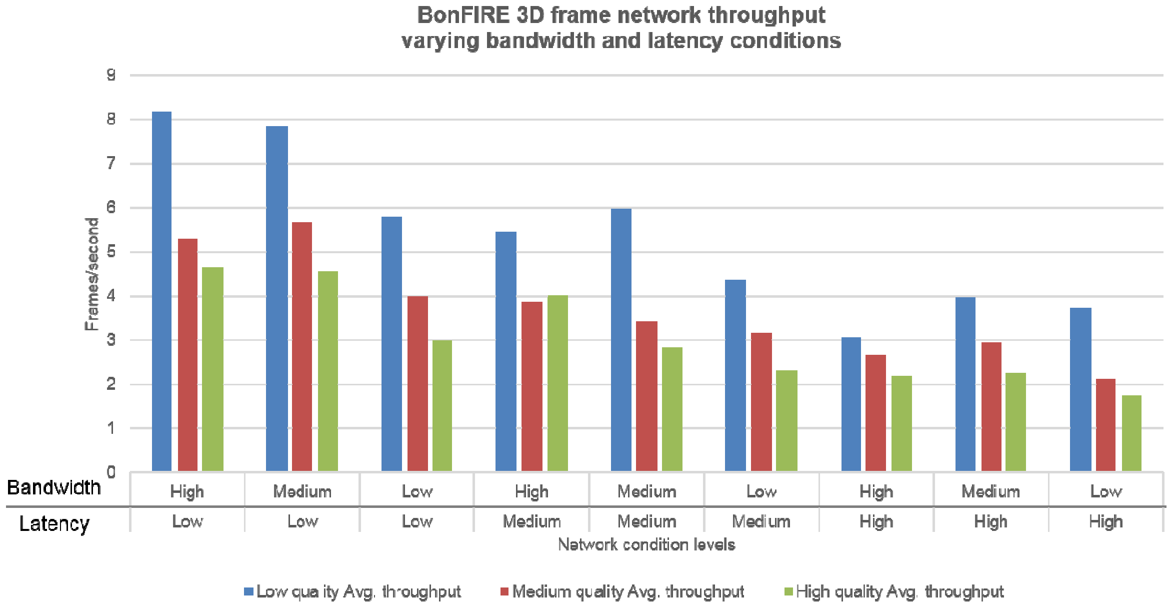

Figure 41: BonFIRE FBR performance results with respect to varying latency and bandwidth

Our BonFIRE results seemed to indicate that available network latency played the most significant role on the overall throughput of 3D frames with bandwidth impacting as a secondary factor. Varying the quality of 3D frame output (and thus effective data size) results in a consistent change of throughput within bandwidth and latency boundaries. We note that this is generally true with the exception of two medium latency conditions (see figure above) where the trend in inverted by a marginal degree. Combined with the in-memory constants derived from the earlier experimentation, the BonFIRE network performance provided us with some indicators about the general behaviour of the reconstruction pipeline and proceed with the design of compression adaptation scheme that could optimise throughput based on available network capabilities (principally latency and bandwidth metrics).

7.3 Real-world network experimentation

The NAS was developed to integrate with the 3D-LIVE game platform; we took steps to replicate a real-world deployment pattern whilst at the same time applying as many reasonable controls over extraneous influences on system behaviour as possible. To realise a real-world network deployment, we set up a 3D-LIVE full body reconstruction environment in Thessaloniki, Greece; a reconstruction receiver game client in Laval, France; the NAS adaptation service in Southampton, United Kingdom and the RabbitMQ server in Germany. To further mitigate against unexpected and difficult to repeat real-world conditions, we created a static, physical model that would be continuously reconstructed at run-time. This constraint provides us with the ability to hold $\lambda 1$ constant at run-time. The experiment procedure and metrics data capture was managed using the on-line experimentation system `EXPERImonitor'.

Experimentation began with a benchmarking process that allowed us to configure the NAS to work within the real-world conditions available to us. The NAS was set up with two network metric monitoring instruments per user: a throughput sampler (based on *iPerf*) and a latency sampler (based on *ping*). Using NAS sampling, we were able to take benchmark values for the best currently available network conditions between the two 3D-LIVE machines, there were:

Table 32: NAS experiment benchmarking

3D-LIVE machine	Latency to Rabbit	Throughput from/to Rabbit
Sender	48.45 ms (average)	12.48Mbits

Receiver	50.8 ms (average	8.398 Mbits (average)

In order to establish some influence over network conditions between the two users, we used Microsoft's Network Emulator for Windows Toolkit[2] (NEWT) to locally constrain network traffic on a single machine (on the sender side) whilst mainlining optimum network conditions on the receiver end. A series of preliminary, exploratory tests using NEWT to change a number of network behaviours whilst streaming live reconstruction data were conducted. During this testing we were unable to replicate (within reasonable parameters) the impact latency appears to impose on overall 3D frame throughput within the BonFIRE environment. It was not until we introduced delays of over 350 milliseconds that we started to see any change to the overall throughput; we theorised that, at least using network emulation tools in real-world networks, only offsets the arrival of in-coming or out-going 3D frames. This lead us to select the bandwidth as the principal factor to investigate as an impact on the transmission of FBR data between users; since the NAS rule engine is flexible and extensible, we were able to re-configure it to be respond to through-put observations accordingly.

Our exploration of this influence was conducted at five bandwidth levels at varying levels of FBR frame data compression. The results provided us with enough data to create a rule set that would allow us define a trial NAS rule set (based on bandwidth metrics) and a nominal threshold below which full body reconstruction would be considered non-viable (this was set a 3fps for the purposes of verifying NAS behaviour, and should *not* be considered as a baseline for acceptable user experience).

[2] From Microsoft Research, ASIA. See https://blog.mrpol.nl/2010/01/14/network-emulator-toolkit/

Bandwidth ceiling		High quality 3D frame	Medium quality 3D frame	Low quality 3D frame
High bandwidth	**12Mbps**	+Quality 6.2 fps	6.6 fps	+Speed 6.4 fps
	6Mbps	6 fps	6.4 fps	6.2 fps
Medium bandwidth	**4Mbps**	+Quality 4.6 fps	6.2 fps	+Speed 6.6 fps
Low bandwidth	**2Mbps**	AVATAR 2.4 fps	+Quality 4 fps	+Speed 4.4 fps
	(1Mbps)	AVATAR 1 fps	AVATAR 1.6 fps	AVATAR 1.8 fps

Figure 42: Configured NAS rules based and benchmarking performance

Figure 42 visualises the rule set that developed for subsequent run-time evaluation trials (see below). The three classification boundaries were mapped to the benchmarking results and the resultant ranges where quality can be traded off for speed indicated. In this simple case, we can see that in high-bandwidth scenarios, high quality FBR frames can be sent at close to maximum performance. As available bandwidth drops, highest quality FBR frames can be maintained, but at the cost of a reduced frame-rate. Finally, in low bandwidth conditions, quality is initially limited and is then dropped altogether once frame rate falls below 3fps.

Run-time evaluations

Once calibrated to real-world network conditions and an updated rule-set, the NAS was integrated with the 3D-LIVE gaming platform to verify system adaptation responses to available network resources. Using the three bandwidth levels as use-cases, we ran the NAS and reconstruction streaming processes and periodically issued commands to either increase the speed or the quality of the full body reconstruction. During this time we observed the rate at which FBR frames arrived at the receiver side and also noted the NAS responses to demands for change in quality of speed.

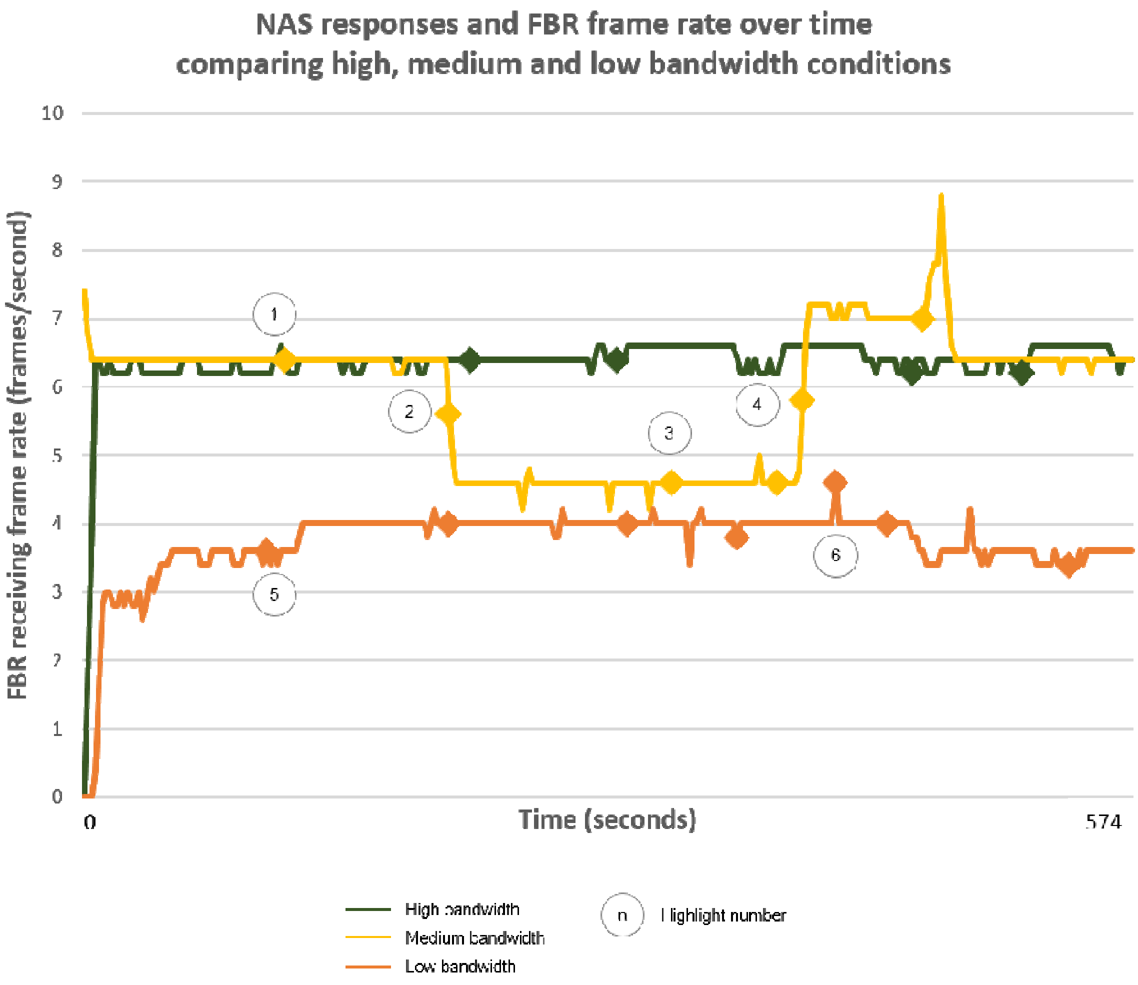

Figure 43: NAS responses and frame rate changes over time in varying bandwidth conditions

Figure 43 visualises FBR receiving frame rate changes over time in each of the three experimental bandwidth levels tested; we indicate the points in each series where changes in quality of speed were requested with diamond markers and selectively highlight points where these changes impact frame rate. Under the high bandwidth scenario, the full range of quality is available at the maximum rate at which FBR frames can be reconstructed by the sending machine: in this case there was no advantage to reducing the quality of frames sent.

Under medium bandwidth conditions we see a much clearer case that demonstrates where dynamically sacrificing quality at run-time can produce improvements in FBR frame throughput. In the table below we enumerate the six QoS medium bandwidth markers, comparing QoS change requests with NAS compression recommendations.

Table 33: NAS QoS requests and compression responses

Marker	QoS request	NAS compression response
1	Quality+	Medium
2	Quality+	Low
3	Quality+	Low
4	Speed+	Medium
5	Speed+	High
6	Speed+	High

Marker and highlight 1 show the first change in QoS changing from an initial \textit{low quality} setting to a medium quality - the NAS responds correctly with a reduction from high to medium compression. At a medium bandwidth level this change of quality can be sustained at the maximum reconstruction frame rate. Highlight 2 (and marker 2) shows the point where we make a further QoS request for quality and in this case compression goes down, but so too does FBR receiving frame rate. The next QoS change request (marker/highlight 3) shows that the system has reached the `floor' of its QoS range and we see no change in performance or quality. Finally for this series, marker/highlight 4 begins a QoS change in the opposite direction towards improvements in speed which eventually return to the `ceiling' frame rate.

A similar pattern for the low bandwidth scenario was also observed, but to a smaller degree. Highlight 5 indicates the point where we request an increase of speed from an initial starting point of medium quality (NAS rules prevent high quality FBR reconstruction in this case). The low bandwidth series continues with attempts to increase speed: here the NAS starts to recommend avatar skeleton data as an alternative (FBR streaming is continued in any case). At the last highlight in Figure 43: NAS responses and frame rate changes over time in varying bandwidth conditions

Figure 43 we show the first request for an improvement in quality - here there was a short delay before changes in frame rate by the receiver were observable.

Our results confirmed that the NAS responded with the appropriate mesh compression recommendations which were affected by the 3D-LIVE full body reconstruction service in real-time in three varying levels of network capability.

8 Discussion

8.1 Summary of experimental outcomes

Here we summarise the outcomes of the 3D-LIVE experimentation as a whole and then proceed with a look at specific scenarios and their evolution within the technical lifecycle of the project. The principal achievements of the experimental work for this project are:

- The successful execution of 9 primary experiments (LIVE1, 2 and 3) with end-users to evaluate UX with a series of 3D-LIVE prototypes.
- The effective application of the 3D-LIVE UX evaluation methodology that captured important user feedback using a rich array of observational techniques.
- Integration with a continuous cycle of improvement of 3D-LIVE design and technical development using an iterative approach of co-creation; development; and experimental evaluation that was bound to user driven requirements.
- A comparative analysis of experimental observations that lead to an understanding of UX factors related to different 3D-LIVE platform configurations and the generation of design heuristics for future system creation.
- Validation of the final 3D-LIVE prototypes as an effective tele-immersive platform through evaluation of system behaviour by end-users, which was generally very positive by the end of the project.

Through experimentation, over the course of the project, we gained a substantial body of knowledge relating not only to what is technically feasible in the deployment of a mixed reality, TI environment in the real world, but also what actually ‘works’ for end-users. The application of our UX methodology allowed us first to develop a foundation for requirements and system design and then progressively track (via the traceability matrix, see below) and refine those requirements as new knowledge became available through experimentation. Our analysis of observations from the user trials allowed us to compare indoor and outdoor user experience that was supported by both ‘low end’ and ‘high end’ technical configurations and drawn conclusions regarding the relative value of these set-ups and offer guidelines for designing with these components in the future. We believe this work provides a substantial body of evidence that validates 3D-LIVE as a TI platform.

Scenario specific outcomes

In the table below we provide a high-level summary the QoE evaluation for the three technical deployment 'tiers' in the 3D-LIVE platform (indoor high-end (HE), indoor low-end (LE) and outdoors) for each of the three 3D-LIVE scenarios:

	Golf	Jogging	Ski
Indoor HE	**N/A**	**Acceptable QoE** High QoS performance put users in a good quality CAVE environment, but this did not significantly push their UX ratings above average.	**High QoE** Consistently very good QoE scores here leading to a high quality UX. Considerations of CAVE deployment costs (compared to Oculus Rift) should be considered however.
Indoor LE	**Good QoE** High scores in UX model during striking part of game play; other less active areas could be improved. For some players, some form asynchronous, semi-immersive application design might be preferred.	**High QoE** Good levels of sense of immersion contributed to by high quality motion and full body reconstruction of the user directly in the virtual environment.	**High QoE** Very good QoE for these users, most notably for the Oculus Rift deployment. Optimisation of the Oculus Rift rendering would be beneficial.
Outdoor	**Acceptable QoE** Some strong TI UX components (such as social interactions and ties) but other areas need improvement	**Mixed QoE** Users felt positioning was consistent with the race; some scored social behaviour highly – however others did	**High QoE** Very good QoE and sense of connectedness with other users. Improvements to the HUD graphics fidelity could enhance UX here.

	before wider acceptance.	not. A much richer virtual environment rendering is needed here.	

Overall we see that the final skiing scenario, which used the most advanced 3D-LIVE prototype provided the highest consistent quality of experience scores for all criteria described in the 3D-LIVE UX model. This is unsurprising since it benefitted from the sum of expertise and technical refinements generated over the course of the project and was the most developed both in terms of UX design and technical implementation. In the other scenarios, we find that advances and improvements in QoS that support high-quality, real-time reproduction of users and actions in meaningful game events generally lead to higher levels of UX. Where support for these elements is lower, QoE responses from our users generally become much more mixed.

8.2 Traceability matrix review & future work

To respond to user needs and requirements, we have proposed to end users an iterative design methodology. During each iteration of collaborative work with end users, we considered a variety of user feedback to generate requirements on the imagined experience. After each iteration we have evaluated the work done and tracked new requirements for the next experimentations loop. Readers are referred to the traceability matrix in appendix J for the full requirements trace that guided development during the project (a full discuss of this matrix is provided in other technical deliverables; see D3.2 and D3.4). For brevity, we have highlight elements of the traceability matrix[3] below with respect to improvements in UX in terms of a) *progression through the project* and b) *future work*.

Progression through the project

UX Model criteria	**QoS component/Matrix IDs**	**Experiment driven change**
Performance gains Exploratory behaviour Social behaviour Technology Adoption	Skeleton capture and activity recognition quality/R0-2,R0-9, R1-2, R1-5, R1-6, R2-2, R2-12, R2-13	Skeleton mapping and occlusions fixed for LIVE 2. Improved consistency for LIVE 2.
Social, empathic and emotional behaviours	Voice communication/R0-1, R0-4, RO-34, R1-4, R2-10	Control over voice streaming introduced in LIVE 2. Switch to Mumble voice chat to improve performance in LIVE 3, particularly reduced latency.
Technology Adoption	Game set-up time/R0-3, R0-32, R2-9	Automatic calibration process included for LIVE 2; further speed-ups in set-up time performed for LIVE 3.
Performance gains	Avatar animation/R0-5	Improved pre-defined animation for LIVE 2.
Performance gains	Improved graphical realism/R0-6,	Improved for LIVE2 and LIVE3.

[3] Note: this is not an exhaustive list from the traceability matrix.

	R0-7, RO-23, R2-11	
Performance gains Exploratory behaviour Technology adoption	Enhanced game-play R0-10,11,12, R0-15, R0-16, R0-18, RO-25, R2-4	Improved game-play set-up for LIVE 2. Enhanced scenarios to increase immersion and social components in LIVE 3.
Performance gains	Full body reconstruction realism enhancements R0-13	Improved for LIVE 2.
Performance gains Exploratory behaviour	Improvements to UX (particularly visualisation) for outdoor users RO-20, 21, 22, R1-1, R2-1	Recon Snow 2 HUD introduced for LIVE 3.

Future work

As part of our concluding analysis of the 3D-LIVE platform, we also suggest the following improvements/extensions for the platform.

- IMU sensors body tracking. 3D-LIVE originally targeted to achieve outdoor body tracking. Existing solutions were too expensive but recently products appeared on the market, providing low-cost solutions.
- Work on HUD capabilities for tele-immersive applications. 3D-LIVE has proven the added value of this technology for tele-immersive ski applications. But this must be investigated in other fields of applications.
- Golf activity recognition: improve the sensors tracking outdoor / find another existing open solution to avoid misdetections of strikes parameters.
- Physiologic sensors: heart-rate sensors have been integrated for the Jogging scenario but have not been experimented yet. It would be useful to have the feedback from joggers on this feature and compare QoE.
- Full Body Reconstruction: Work on both the reconstruction and streaming algorithms and protocols to enhance the quality of the remote reconstruction.

8.3 Impact on TI design perspective

In this final phase of user driven, experimental evaluation we were able to enhance the understanding of user experience in mixed reality, tele-immersive environments from a number of important perspectives:

- Influential QoE constructs
- Game and scenario design
- Important QoS criteria

We have identified three key UX QoE criteria that, when supported by good design decisions, combined to characterise immersive UX in TI environments: *exploratory behaviours*; *performance gains* and *social behaviours*. Our development and experimentation with the 3D-LIVE environment has shown that design decisions should carefully consider the shaping of *meaningful actions and events*; the *balancing of user focal attention* on game interactions; and the provision of time for *shared reflection* of interactive events. Finally we offer recommendations for QoS priorities for mixed reality TI system like 3D-LIVE; these relate to the *provision of motion capture and activity recognition*; *rapid spatial data updates*; the *value of high levels of visual realism*; the importance of *keeping visual and audio latency low*. In addition to the full LIVE 3 user trials we have also compared experiences specific indoor technologies (HUDs compared with CAVE) and evaluated an adaptive data compression methodology and system prototype (the Network Adaptation Service) for the optimisation of full body reconstruction streams in a TI environment.

8.4 UX methodology review

The real-world experimental context of the 3D-LIVE platform and the rapid *design-prototype-evaluation* methodology adopted provided the consortia with the most flexibility with which to refine the system design and evaluate actual user experience. The strengths of this approach are:

- Rapid and direct feedback of actual use in both laboratory and real-world settings
- Set-up of a complex, distributed prototype system manageable
- Rich set of observations for qualitative assessment of UX
- Trials can be conducted at a cost consummate with resources available in the project

In designing and executing the LIVE3 trials, we re-focussed the design and reduced the number of experimental observations (compared with LIVE2) to focus more narrowly on aspects of UX that relate particularly to immersion in a TI environment. As a result we were able to follow up on specific improvements defined as a result of earlier experimental work and gather a rich array of QoE data. Our approach strategically addressed those UX constructs that were found lacking from earlier 3D-LIVE trials and sought to understand these improvements by catching a rich set of QoE observations from relatively small user groups. Whilst taking this approach has yielded a number of important findings, we also recognise the following limitations of this methodology:

- Current experimental data cannot drive significant statistical analysis
- Real-world contexts and complexity of interrelated system modules make independent variables very difficult to control
- The large number of variations in experimental conditions present a enormous challenge to systematically evaluate

Nevertheless, we believe that on balance, our approach has revealed *real-world* behaviours that provides evidence validating many of the design and technical decisions taken in this project. Furthermore, this exploratory work has led to a number of important experimental hypothesis that could be perused in more controlled experimental conditions to advance understanding of specific UX factors (see section 6.6.1).

8.5 Feedback on the adopted UX methodology

At the end of the different cycles of UX design along the overall 3D LIVE life cycle, we are in a position of assessing the benefits which were achieved by deploying it as well as what could be done next, to make sure that the methodology is adaptable to other contexts, such as other FIRE domains or similar (such as Living Labs).

In this section, we have therefore offer the reader two distinct views: one reporting the internal feedback from our experience got in the implementation of the 3D LIVE project; the second relevant to the outcomes of the involvement of external stakeholders, who were interviewed on the proposed methodology as well as the perceived applicability to different and/or adjacent contexts.

8.5.1 Results and lessons learnt on 3D LIVE UX methodology and UX design process

The specific outcomes of the 3D LIVE projects are described in details in the different deliverables. In this section, we would like to focus specifically on the overall 'grand' results as well as *lessons learnt* which can be directly associated to the use of the UX methodology and UX design process for the design of Future Internet applications.

Among the others, we can reasonably say that the use of 3D LIVE UX model and UX design process allowed us to achieve:

Much better definition of user scenarios. Users were engaged and involved in the design process since the beginning. The initial engagement with the users was achieved on the basis of initial use scenarios, which were derived internally on the basis of the different views represented inside the consortium's partner group. The adopted strategy has been to make the users focus only on scenarios, irrespectively from technology, in order for them to predict, anticipate and explore the experience before actually trying it first-hand. By doing this, we developed scenarios which truly represented their needs and, therefore, the design team could focus only on what really mattered, resulting in significant savings on the design efforts. Future activities could therefore focus on the assessment of such savings originated by the 3D LIVE UX approach, in order to support the adoption of UX based techniques on regular basis in Future Internet contexts.

Excellent engagement of users, on the basis of concrete and understandable scenarios. Quite related to the previous point, the adoption of understandable scenarios allowed to engage users on topics they need. This was key as users, although some of them could be technology savvy, were not always able to discuss the technological details. We regarded them as technology agnostic. The opportunity of focussing only on the scenarios and having when requested explanation of the supporting technology made the selected users feeling part of the development process, as it was evidenced by the request of being updated on 3D LIVE development. While a sort of animation and motivation activity was a bit outside the scope of the work for 3D LIVE, we believe that future activities could benefit from an optimised community support activity, which could ever improve the users engagement level (i.e. organisation of social events and feedback). Potential legal issues will need to be sorted out, in case users' feedback and/or input brings to the achievement of additional IPR.

Capability of performing sensitivity analysis. One of the advantages of the 3D LIVE UX model is that it allows for the experience associated to each scenario element to have a fixed although subjective way of parametrising the experience. While the debate on the absolute values of the metrics can be endless, it is worth noting that the real interest is in the variation of the subjective assessment of experience. This allows to have fair comparison between alternative solutions proposed (i.e. High End vs Low End configurations) and to take rational decisions based on that. This approach can be also used in order to perform sensitivity analysis with respect to different target groups, in order to better align the offer to targeted groups. Savings can be achieved on the basis of sensitivity analysis, the amount of which are of course depending upon the specific case. The availability of this feature would also allow a better planning of the design effort, which can be effectively supported by such decision mechanisms to solve design dilemmas.

Increased credibility of the designed applications. The adoption of the 3D LIVE UX approach can be also seen as an initial validation and acceptance of the proposed applications and services. Although the 3D LIVE package is still in a validated but prototypical stage, it can be fairly said that, thanks to the feedback of the users, it constitutes an optimised basis for further development. As understood from the on-going contacts to exploit 3D LIVE, potential partners are happy that what was produced was thoroughly tested with users, this resulting in an increased exploitation potential.

As far as lessons learnt are concerned, a selection of the most important ‘takeaways’ (at least in our opinion) is reported hereafter:

Users must be carefully led through the process of co-creation. Some approaches obviously overestimate the real extent of the contribution offered, these approaches tend to deny that users can have positive contributions at all. Our experience in 3D LIVE is that, as Latins used to say, *“In medio stat virtus”*, meaning that virtue always stays in the middle. Our position is that the contribution of users is indeed extremely valuable, but that in order to achieve that, users should be put in a position of being able to provide input. Users can contribute by anticipating or evaluating an experience and sharing their background of past experiences, which are variegated and possibly uncorrelated with the objective of their involvement. They can say if they like or not a specific scenario and suggest improvement to it, it is much less unlikely however that they can devise themselves a use scenario. Users must be therefore be guided in the process of co-creation and experimentation and alternatives must be prepared beforehand, in order to be able to make the most out of their suggestion. We found that this process is a difficult mix between allowing total real user driven design innovation and more structured, 'guided' patterns.

Iterative process for updating User eXperience description. Within 3D LIVE, the assumption was that users' involvement is theoretically a continuous exercise, which we divided in four phases: *co-creation*; *exploration*; *experimentation* and *evaluation*. We realised that user's perceptions are indeed affected also by the level of maturity of the proposed applications, meaning by this that anticipating an experience could have different results when that experience will materialise at a later stage of the project. Evolving from initial to more mature descriptions of the UX is therefore quite a natural process. Taking into account in a proper way the output this process produces is a powerful tool. Design process needs to be adapted to cope with it and could lead to a differently conceived schedule for the overall design plan. Be ready to accommodate iteration into it.

Users can adapt better than you think to 'Beta' solutions. Our experience in 3D LIVE is that, when properly led, users can react quite positively and proactively to prototypical solutions. They generally understand the reason why a mock-up is proposed and how to deal with that. Again, our lesson learnt here is that you need to prepare the evolution scenario, so that to put users in a position to work around it.

Overrule users' prejudice! In the previous paragraphs, we have been generally positive about the contribution that users can do. However, in some particular case, we were faced by the fact that users expressed themselves against some proposed solutions, specifically when new technologies are involved (like for instance the Recon glasses, as they perceives as the technology was not mature enough, or creating uncomfortable feelings or simply as not safe). Our lesson learnt in this respect is that you have to be ready to be provocative and to challenge users suggestions, as they reflect their current background and experience and, if the case, to propose it under different conditions.

8.5.2 Validation of 3D LIVE UX methodology and design process

Based on the positive outcomes of the design and testing activities supported by the 3D LIVE UX approach, the 3D LIVE consortium organised a public event, with the objective of disseminating the UX methodology and design process and to get feedback on it from an audience of UX and FI experts and practitioners. The event consisted in one plenary session organised within the Annual ESoCE-Net Industrial Forum, which was held in Rome on 1st Dec. 2014, just after Live 3 Jogging and before Live 3 Skiing. The progress of the activities and the relevant outcomes, although informal were enough to properly organise the session (which is fully reported in D5.3). The audience consisted of about 50 people, most of them involved in open innovation issues and related domain. A number of 'Living Labbers' were attending, in view of analysing the described methodology to be adapted to the needs of their specific constituencies and in the different business domains / contexts.

Benefits deriving from the adoption of the 3D-LIVE UX methodology were reported and discussed with the audience in a structured way, in order to obtain feedback on it and investigate on the potential applicability of the 3D LIVE methodology to different contexts. In addition to this, we proceeded with interviewing 5 experts who accepted to review with us the approach adopted, on the basis of the detailed presentation given, integrated with additional information provided.

In particular, the following areas were investigated:

- Efficiency of Users' engagement. Based on the information provided, a feedback was requested on the overall UX process and on the meaningfulness of the described UX metrics;
- Added Value of Users' engagement. Based on the described project outcomes, an evaluation of the added value provided by the users on the project outcomes was done, based also on the individual experience of users' engagement;
- Applicability of the proposed approach to other FIRE, FI and Living Labs style context. We wanted to investigate under which circumstances the 3D LIVE UX approach can be generalised and adopted in other contexts.

We address each of these areas in turn.

Efficiency of Users' engagement.

Engagement process

The selected experts were quite positively impressed by our process for engaging and involving the users in 3D LIVE design process, all of them concurred that the adopted stepwise approach ensured that as users were asked to contribute to topics they know. One of the basic problems which practitioners do encounter when adopting UX based technique is that discussions with users end up to be too broad, thus producing two types of problems:

a) users sudden loss of interest; b) difficulty in maintaining some specific focus and therefore in extracting meaningful recommendations. In the 3D-LIVE approach, using specific scenarios with familiar real-world behaviours, we were able to maintain focus with our users.

Scenario based approach

It is also confirmed that the scenario based approach is the right one, as also the other practitioners confirmed that users just focus on the potential uses and have little interest in the underlining technologies.

Users' identification

It was observed that, depending upon the type of applications to developed, a more refined identification of homogeneous groups of users could be carried out, in order to take into account different and potentially contrasting needs from different stakeholders, which would need to be reconciled. It was also pointed out that the initial identification of the users' groups should be done in relation to the appraised market requirements (i.e. so that to collect needs that matter to the potential customers), which was only partially done within 3D LIVE. In our case, the complexity of our real-world technical deployments and necessary experimentation procedures significantly reduced the scope of user recruitment possible.

Users' contribution.

As far as the way users are engaged along the whole life cycle, the fact that users changed along the design iterations was considered not only sensible, but also desirable as it was suggested that new users always bring new stimuli for the design team (experience suggests that users can take things a bit of granted after the first round of contribution. The only caveat they put is to keep the consistency between users typology, so that overall the same needs are expressed, explored and validated.

UX Model

Finally, the availability of a UX model was considered essential in order to have some reference description of the experience, already elaborated (a priori) in order take into account the different elements who contribute to the experience, with the view of helping UX designers to quickly converge to the selection of the most important UX elements. The presented 3D-LIVE UX model was deemed as appropriate and representative of the most important aspects contributing to the experience, specifically the "twilight" tele-immersive experience. Possible extensions to cover specific cases if required were deemed as not affecting the overall model concept (see also extension to other domains).

Added Value of Users' engagement.

In this section, the experts interviewed discussed with us where they see the added values of users' engagement for their cases.

- Exploration of different configurations and/or set-ups before entering the design phase. This aspect is important not only for defining the right configuration since the beginning, but also to minimise the implementation effort in case of IT services, as in the manufacturing case. Our experiences with users during live field trials provided us with considerable insight into how system configuration can be optimised for mixed reality TI systems.
- Capitalising on users' knowledge/experience. The added value of users' engagement is not only in the collection of new requirements in case of users as potential customers, but especially in capturing users' background in case users are stakeholders as well. In the manufacturing sector, users (in this case, line or workshop operators) experience is key for process improvement.
- Added value is not always achieved since engagement methods are not always formalised and optimised. Many claim that user engagement is key for success and that it is adopted as formal, best practice. Added value is achieved only when the method used is formalised (as with the 3D-LIVE UX modelling and experimentation process), both with respect the elements contributing to user's experience and/or satisfaction and also with respect of optimisation of interaction time with users. Methods for effectively involving users (using formal approach) are otherwise missing.
- Increasing the acceptance and usability of the final product or service in design, production or service ecosystems. Engaging or involving the users in the design, development and evaluation of an application or services has always the added value of increasing the acceptance and usability of the final product. This facilitates the implementation process, both in terms of effort and time required.

Applicability of the proposed approach to other domains.

The applicability of the proposed approach was discussed in relation to potential application in other specific domains, such as manufacturing and health service ecosystems. Additional domains were discussed (such as design service based Living Labs and additional sporting community), however the level of maturity of such environments was not so advanced and the discussion remained inconclusive. As far as a manufacturing ecosystem is concerned, the potential applicability of the proposed approach was discussed in relation to apply the 3D LIVE UX methodology to business process improvement for a given production line, the users being here the people working along the production line. Conclusions of the discussion were that:

- It is believed that the 3D LIVE UX model can be adapted with a reasonable effort to the considered domain, the adaptation implying less focus on the 'twilight zone' and tele-immersion but more on the users' satisfaction and system usability;
- Potential need to correlate the UX QoE metrics with business operation metrics (KPI), especially in the production domain where a better experience or satisfaction of the user needs to be necessarily related to an increased efficiency of the overall process.

One of the main factors in favour of adopting this approach in this context is that it may help to close the gap between users (line managers and operators) and stakeholders, who often adopt simulation formalisms which are not user-friendly or clear.

As far as the health ecosystems is concerned, the idea was to consider designing and testing IT health applications, together with the final users. It was concluded that our approach is perfectly transferable not only to this but also to any other domain where IT based applications are to be developed. It was perceived that the methodology will require some adaptations in terms of the elements to be considered both in the QoE and QoS dimensions to complement the existing ones. The inclusion of QoS elements as important dimensions to be considered when designing, developing and evaluating the user experience can be considered quite innovative when correlated to QoEs. Although already present in the 3D-LIVE UX model, some more focus on usability (from a user perspective) would be interesting.

All our experts believed that this approach can also reduce the final costs of the implemented solution, especially if a non-costly option is identified from the very beginning as a suitable solution.

In conclusions, we can summarise as follows:

- Adaptability of the 3D LIVE approach to other domains looks not only feasible but also promising;

- Focus on other elements of the experience may be required and adaptation is perceived to be achievable
- Benefits resulting from the adoption of the 3D LIVE methodology are believed to be tangible and exploitable.

9 Conclusion

In concluding this experimental work for the 3D-LIVE project we are able to report on the successful execution of three primary user trials using the final system prototypes as well as additional experiments to evaluate user experience using high-end graphical rendering techniques and a QoS optimisation strategy for full body reconstruction data compression and transmission. Our results, based on a range of qualitative and quantitative observations, have provided us with a range of insights that have allowed us to both validate the use of the 3D-LIVE system in the real-world and also better understand the factors that impact user experience in a tele-immersive environment.

In totality for the project we have been able to achieve:

- The successful execution of 9 primary experiments (LIVE1, 2 and 3) with end-users to evaluate UX with a series of 3D-LIVE prototypes.
- The effective application of the 3D-LIVE UX evaluation methodology that captured important user feedback using a rich array of observational techniques.
- Integration with a continuous cycle of improvement of 3D-LIVE design and technical development using an iterative approach of co-creation; development; and experimental evaluation that was bound to user driven requirements.
- A comparative analysis of experimental observations that lead to an understanding of UX factors related to different 3D-LIVE platform configurations and the generation of design heuristics for future system creation.
- Validation of the final 3D-LIVE prototypes as an effective tele-immersive platform through evaluation of system behaviour by end-users, which was generally very positive by the end of the project.

Directly resulting from this work, we were able to evaluate the 3D-LIVE system in terms of future work that could lead to a technical platform that could be used for 3rd party exploitation. In addition to this, we are able to propose design and development heuristics that provide guidance for practitioners/developers in the field of TI environments based on our findings. Finally, we provide a critical evaluation of the value of the user-centred, co-creation methodology we used in the project and offer recommendations for its application in other domains.

10 Appendix A: LIVE 3 detail experimentation workflows

1	Experiment set-up task	Who	Status
2	Synchronize clocks	All	W
3	Start of experiment set-up	IT INNOV	W
4	User briefing/consent task (indoor A)	Benjamin	W
6	User briefing/consent task (outdoor)	Benjamin	W
7	Start ECC dashboard	IT INNOV	W
8	START OF EXPERIMENT		W
9	Create experiment	IT INNOV	W
10	Start ERS service	IT INNOV	W
11	Check ERS connection to ECC	IT INNOV	W
12	WAIT until tasks complete		W
13	Start/Check Indoor Sensor Exel app	Benjamin	W
14	Start ARTS Kinect capturer	Benjamin	W
15	Check Kinect capturer connections to ECC	IT INNOV	W
16	WAIT until tasks complete		W
17	Check Unity server settings	Benjamin	W
18	Start Outdoor 3DLIVE app	David	W
19	Start indoor app in France (enter username)	Benjamin	W
20	WAIT until tasks complete		W
21	Outdoor golfer at start of course	David	W
22	Outdoor user: Press GO button	David	W
23	Start FRAPS on indoor app	Benjamin	W
24	Indoor user: Press GO button	Benjamin	W
25	Check Unity server ECC connection	IT INNOV	W
26	WAIT until tasks complete		W
28	Check ECC metrics	IT INNOV	W
29	Set up completed		W
30	Outdoor golfer at start of course	David	W
31	Trigger game start	Benjamin	W
32	Indoor takes first shot	Benjamin	W
33	Outdoor takes next shot	David	W
34	Outdoor goes to his ball (indoor follows)	Benjamin	W
35	They talk to choose the best ball	Benjamin	W
36	They replace their ball to the selected pos	Benjamin	W
37	return to [29]		W
38	Shots Status	Benjamin	W
39	Ball in Hole !	Benjamin	W
40	WAIT until tasks complete		W
41	Confirm game complete	Benjamin	W
42	OPTION to return to [32]		W
43	Teardown & finalise experiment	IT INNOV	W
44	Save metric data	IT INNOV	W
45	Save Unity 3D server logs	Benjamin	W
46	WAIT until tasks complete		W
47	Update Results sheet	All	W
48	Stop Unity Server	Benjamin	W
49	Stop ARTS Kinect capturer	Benjamin	W
50	Check Unity/Kinect clients ECC disconnection	IT INNOV	W
51	Create new experiment	IT INNOV	W
52	Go to [15]		W
53	Shutdown software	All	W
54	User de-briefing/questionnaire (indoor A)	Benjamin	W
56	User de-briefing/questionnaire (outdoor)	Benjamin	W

Golfing

1	Experiment set-up task	Who	Status
2	Synchronize clocks	All	W
3	Clear RabbitMQ server	CERTH	W
4	Start of experiment set-up	IT INNOV	W
5	Start ECC dashboard	IT INNOV	W
6	START OF EXPERIMENT		W
7	User briefing/consent task (indoor A)	CYBER	W
8	User briefing/consent task (indoor B)	CERTH	W
9	User briefing/consent task (outdoor)	CYBER	W
10	Create experiment	IT INNOV	W
11	Start ERS service	IT INNOV	W
12	Check ERS connection to ECC	IT INNOV	W
13	WAIT until tasks complete		W
15	Start CYBER Kinect capturer(s)	CYBER	W
16	Check Kinect capturer connections to ECC	IT INNOV	W
17	Start CERTH Kinect capturer(s)	CERTH	W
18	Check Kinect capturer connections to ECC	IT INNOV	W
19	Confirm FBR compression rate (High/Low)	CERTH	W
20	WAIT until tasks complete		W
21	Start Outdoor 3DLIVE app	CYBER	W
22	Start Outdoor EOS app	CYBER	W
23	Start indoor app in Oulu	CYBER	W
24	Start indoor app in Greece	CERTH	W
25	WAIT until tasks complete		W
28	Check indoor app clients ECC connection	IT INNOV	W
30	Indoor CERTH user: AMQP Settings->Remote1 -> Reconstructed (FBR only)	CERTH	W
33	WAIT until tasks complete		W
34	Check ECC metrics	IT INNOV	W
35	Set up completed		W
36	Outdoor jogger at start of course	CYBER	W
38	Confirm all joggers running	CYBER	W
39	All Joggers reached mid-point	CYBER	W
40	FBR compression rate changed	CERTH	W
41	All Joggers running to the finish	CYBER	W
42	WAIT until tasks complete		W
43	Confirm course completed	CYBER	W
44	Stop experiment	IT INNOV	W
45	Disconnect all ECC clients	ALL	W
46	Save metric data	IT INNOV	W
47	Save RealXtend server logs	CYBER	W
48	WAIT until tasks complete		W
49	Update Results sheet	All	W
50	Shutdown software	All	W
51	User de-briefing/questionnaire (indoor A)	CYBER	W
52	User de-briefing/questionnaire (indoor B)	CERTH	W
53	User de-briefing/questionnaire (outdoor)	CYBER	W

Jogging

1	Experiment set-up task	Who	Status
2	Start of experiment set-up	IT INNOV	W
3	Synchronize system clocks	ALL	W
4	User briefing/consent task (outdoor & indoor A)	IT INNOV	W
5	User briefing/consent task (indoor B)	CERTH	W
6	Start Mumble Server	ARTS	W
7	Start ECC dashboard	IT INNOV	W
8	Start ERS service	IT INNOV	W
9	Check ERS connection to ECC	IT INNOV	W
10	START OF EXPERIMENT		W
11	Create experiment	IT INNOV	W
12	Outdoors Internet/GPS/Mumble check	IT INNOV	W
13	Start Unity game server	ARTS	W
14	Start Outdoor 3DLIVE apps	IT INNOV	W
15	Start Indoor A application	IT INNOV	W
16	Start Indoor B application	CERTH	W
17	Confirm all users connected to game server	ARTS	W
18	Confirm all ECC metrics in-coming	IT INNOV	W
19	WAIT until tasks complete		W
20	Outdoor skier in meeting zone	IT INNOV	W
21	Meeting between players completed	ALL	W
22	WAIT until tasks complete		W
23	Outdoor skier in race start zone	IT INNOV	W
24	Outdoor skier entered race	IT INNOV	W
25	Set up completed		W
26	Race started	ARTS	W
27	Outdoor player at finish line	IT INNOV	W
28	Indoor A player at finish line	IT INNOV	W
29	Indoor B player at finish line	CERTH	W
30	WAIT until tasks complete		W
31	Race review completed	ALL	W
32	Finalise experiment	IT INNOV	W
33	Save metric data	IT INNOV	W
34	Save log/picture/video data	ALL	W
35	WAIT until tasks complete		W
36	Update Results sheet	All	W
37	Outdoor user questionnaire/debriefing	IT INNOV	W
38	Indoor A user questionnaire/debriefing	ARTS	W
39	Indoor B user questionnaire/debriefing	CERTH	W
40	Stop Unity & Mumble Servers	ARTS	W
41	Stop Indoor A Kinect capturer	ARTS	W
42	Stop Indoor B Kinect capturer	CERTH	W
43	Check client ECC disconnection	IT INNOV	W
44	Go to [10]		W
45	Shutdown software	All	W

Skiing

11 Appendix B: LIVE 3 QoS metrics glossary

11.1 Motion capture related metrics

Skeleton Confidence (%)

This should be interpreted as the overall confidence on the accuracy of the captured users' skeleton. OpenNI SDK reports confidence values for each skeleton joint independently. This metric is calculated as the average confidence among all joints of the skeleton. Higher values indicate better confidence.

Skeleton Quality (mm)

This is a metric aiming to measure the quality of the skeleton of the captured user. Each skeleton joint reported by OpenNI SDK contains X,Y and Z coordinate values. All the joints of the skeleton are back projected on to the captured depth map and the difference between the joint's Z coordinate and the depth value at the projected pixel is calculated. The sum of those differences among all different joints of the skeleton constitutes the Skeleton Quality metric. The lower the values, the better the skeleton quality.

Skeleton Jerkiness (X,Y,Z) (mm)

This metric aims to capture the overall skeleton jerkiness. Mathematically it is equivalent to the sum of standard deviations of each joint's position over a running window of 1 second, independently on each axis. The sum of the deviations among all joints, separately in each axis, constitutes the overall skeleton jerkiness.

11.2 Avatar related metrics

Avatar virtual X and Z-location (3D world coordinates)

This metric refers to the current X and Z-location of the avatar in the virtual Oulu venue. Avatar moves in XZ-plane and returned value is Z-value of the position data.

Avatar virtual longitude and latitude location (digital degrees)

This metric displays the current virtual avatar location in terms of their projected longitude and latitude. Virtual longitude and latitude is calculated by transforming XZ-position to latitude/longitude coordinate system using reference points in real world and virtual world.

Number of avatar collisions (count)

This metric refers to the amount of collisions controlled avatar has made with other avatars in the virtual venue. Returned value is total number of frames with collisions detected.

Average Mesh Compression Ratio

The Mesh Compression Ratio is defined as the fraction with nominator the compressed size of the mesh in bytes and denominator the uncompressed size of the same mesh in bytes as well. This metric captures a running average of mesh compression ratio across all frames of the experiment up-to the point where the metric was captured.

Reconstruction frame rate (fps)

This metric captures the number of frames being reconstructed at the unit of time.

Reconstruction Streaming frame rate (fps)

The reconstruction streaming frame-rate metric captures the number of frames streamed from the reconstruction site to the RabbitMQ server at the unit of time.

Reconstruction Receiving frame rate (fps)

The reconstruction receiving frame rate metric captures the number of reconstructed frames received at the receiver side from the RabbitMQ server at the unit of time.

Average Mesh Compression Time (sec)

Mesh Compression time is defined as the computational time it takes to compress the mesh of one frame. This metric captures the running average of mesh compression time from the beginning of the experiment up-to the point where the metric was captured.

Compression Framerate (Frames per second)

This metric captures the number of frames being compressed at the unit of time.

Reconstruction Instantaneous PSNR (dB)

This metric captures the PSNR of the reconstructed mesh vs a natural image taken from an RGB camera as a means to evaluate the reconstruction visual quality. This value is Instantaneous

Reconstruction Sequence PSNR (dB)

It is the same metric as Reconstruction Instantaneous PSNR but calculated over the whole sequence as if it was a video.

Compressed Reconstruction Instantaneous PSNR (dB)

This metric captures the PSNR of the compressed reconstructed mesh vs a natural image taken from an RGB camera as a means to evaluate the compressed reconstruction visual quality. This value is Instantaneous.

Compressed Reconstruction Sequence PSNR (dB)

It is the same metric as Compressed Reconstruction Instantaneous PSNR but calculated over the whole sequence as if it was a video.

11.3 Network performance related metrics

Skeleton data package throughput (packages/second)

This metric describes the data rate of skeleton animation data arrived through AMQP-protocol to 3D-LIVE client. The value returned is an average data packages per second.

Propagation delay of GPS data (ms)

This metric refers to the propagation delay of GPS data from outdoor user’s smartphone to the indoor user’s client. Returned value is milliseconds.

Reconstruction Streaming Frame Rate (Frames per second)

This metric captures the number of frames being streamed to the network at the unit of time at the capture site.

Propagation delay of GPS data to display (ms)

This metric refers to the propagation delay of GPS data from outdoor user’s smartphone to the display of indoor user’s client. Propagation to display is considered complete when outdoor avatar moves to the reported position of the GPS in the virtual world. Returned value is milliseconds.

Average skeleton data propagation time from other clients (ms)

This metric displays average skeleton data propagation time from other clients to the client reporting these measurements. Returns average value in milliseconds.

Skeleton data propagation delay to display (ms)

This metric describes skeleton data propagation delay from the Kinect sensor to 3D-LIVE client display. Returns time in milliseconds.

11.4 Common 3D-LIVE client application metrics

Frame rate of client (frames/second)

This metric shows the current frame rate of the 3D-LIVE client (indoor or outdoor). Returned value is a smoothed average over the period of one second; the system automatically caps performance at 60.

Number of sensory channels (count)

The number of sensory channels made available to the user through which interaction is made possible.

Display resolution (X by Y pixels)

The resolution of the display presented to the indoor/outdoor user.

11.5 Outdoor 3D-LIVE client application metrics

GPS accuracy (m)

This metric refers to the GPS accuracy of the outdoor user's smartphone device. GPS accuracy data is reported by the Android OS and value returned is average error in meters.

GPS longitude and latitude location (digital degrees)

This metric displays jogger's real longitude and latitude-coordinate reported by a smartphone GPS-sensor.

11.6 Effect Query Service performance metrics

Effect query count (nominal count)

Used to track how many of each specific environment effect query was made during an experiment; each nominal value (such as 'WIND_EFFECT' or 'ILLUMINANCE_EFFECT' is time-stamped at the point when the query was received.

Effect query sent count (nominal count)

Used to track the type of effect (result) sent by the ERS to the render engine. Each effect result is time-stamped (and can be paired with the query count), providing an overall calculation time for each query/result.

Effect query rate (requests/min)

Used to track the rate at which queries are received by the ERS system by a 3D-LIVE rendering engine.

11.7 Effect Query Service environment metrics

The environmental modeller aggregates measurements from multiple clients and performs a spatial interpolation from the appropriate set when queried by the 3D-LIVE rendering engine. The method of interpolate (inverse distance weighting) is described below; the interpolated metrics based on the ERS sample data are (when available from sources):

- Temperature (centigrade)
- Humidity (relative %)
- Rain (mm/minute)
- Wind (speed: mph; direction: degrees)
- Snow fall (mm/minute)
- Luminance (lux)

Modeler: Inverse distance weighting (IDW) function

The Inverse Distance Weighting (IDW) function [1] was chosen for use in the 3D-LIVE environment modelling module as it satisfies the requirements for a real-time response to changes during game-play and its wide-spread application in the geospatial modelling literature [2]. The IDW function used here is defined as:

$$P_i = \frac{\sum_{j=1}^{G} P_j / D_{ij}^n}{\sum_{j=1}^{G} 1 / D_{ij}^n}$$

In which P*i* and P*j* are properties at the target and source locations respectively. Dij is defined as the distance between locations *i* and *j*. G represents the total number of sampled source locations; n provides the distance weighting power (controlling region of influence).

[1] Lam, N.S. (1983) Spatial interpolation methods review. The American Cartographer 10: 129-149

[2] Li, J., Heap, A.D. (2011) A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. Ecological Informatics 6 (2011) p228-241

11.8 Voice chat server metrics

Average packet loss (indoors to outdoors) (% sent/received)

The packet loss regarding voice data from one indoor user machine to the remote outdoor user machine.

Average packet loss (outdoors to indoors) (% sent/received)

The packet loss regarding voice data from one outdoor user machine to the remote indoor user machine.

11.9 Outdoor/Indoor voice chat module metrics

Voice chat total packets received (count)

The number of packets received regarding voice data by any user machine.

Voice chat total size of packets received (bytes)

The size in bytes of the packets received regarding voice data by any user machine.

Voice chat total packets sent (count)

The number of packets sent regarding voice data by any user machine.

Voice chat total size of packets sent (bytes)

11.10 The size in bytes of the packets sent regarding voice data by any user machine.

11.11 Scenario specific metrics

Indoor golf shot sent time (time stamp, ms)

The time delay of the transmission of the indoor shot information (golfing scenario) to the outdoor application.

Indoor golf shot received time (time stamp, ms)

The time delay of the transmission of the outdoor shot information (golfing scenario) to the indoor application.

Skiing game state (time stamp, ms)

During game play, the game engine sends nominal data representing the time when the game progressed through the updated scenario, this includes the times when users were interacting on the start line; when the race count-down began; and when all users were at the finish line reviewing the race.

11.12 Unity renderer log metrics

GPS Position Sent – Received delay (ms)

The latency between the moment a new GPS location information is available on the outdoor mobile device and the moment the indoor application acknowledges that information.

GPS Position Sent – Displayed delay (ms)

The latency between the moment a new GPS location information is available on the outdoor mobile device and the moment the outdoor avatar inside the indoor application reaches the new target position

GPS Position Path Accuracy (m)

The Accuracy between the path followed by the outdoor avatar in the virtual world, and the interpolated path calculated in post processing from GPS locations of the outdoor user.

12 Appendix C: 3D-LIVE user consent form

3D-LIVE User Consent Form (January 29th-30th 2015)

Today we are going to test a prototype version of the 3D-LIVE system that allows remotely connected users to share a sports related experience in a virtual environment. You will participate as a user and be asked to interact with 3D-LIVE hardware and software: its operation will be explained carefully to you by members of the 3D-LIVE team. Before starting the experiment, a member of the 3D-LIVE team will also describe what it is you will be asked to do and provide you with guidance on safety during experimentation.

Privacy Policy

The 3D-LIVE project protects and makes confidential all data we collect about you during the course of this experiment in accordance with appropriate data protection law. We will take the following steps:

- No information that can personally identify you will be stored in combination with your survey and test data.
- All survey and test data collected from you will be stored anonymously using IDs (such as 'user 1' or 'cf5d5f00-a944-11e3-a5e2-0800200c9a66').
- None of the data we collect from you will be shared with partners outside of the 3D-LIVE project[1].
- All data collected from you will be destroyed after the end of the 3D-LIVE project.
- Anonymized data collected from participants will be collectively analysed and interpreted during the course of the project; the results of this analysis may be publicly reported.

Disclaimer

I have agreed to participate in using the 3D-LIVE system today and understand that I am able to cease my participation at any time.

I hereby confirm that I desist from any claims for damage or liability against 3D-LIVE partners in conjunction with the usage of the 3D-LIVE hardware and software I will use today.

[1] For a list of the 3D-LIVE partners, please see the next page.

I am aware that I put myself in a potentially unfamiliar situation by using 3D-LIVE technology and that personal injuries cannot be excluded.

I declare that I am willing to participate in this experiment and do so totally at my own risk. In case of damage caused in conjunction with use of the 3D-LIVE experiment, I will not blame any of the 3D-LIVE partners in as far as the damage is not linked to gross negligence of the 3D-LIVE partners.

I declare that I do not suffer any health impairments that, in using the 3D-LIVE technology today, will impair my ability to drive or operate machinery.

I give permission to the 3D-LIVE partners to use video material of me captured during the experiment in reports and publications: YES/NO. *(Please mark appropriately)*

I have read and understood the above privacy and disclaimer statements and agree.

LOCATION: ……………………………………………………

DATE: ……………………………………………………

Signature: ……………………………………………………………………………

Name (in CAPITAL letters): ………………………………………………………………………

List of 3D-LIVE Partners

- Collaborative Engineering (Italy)
- Information Technologies Institute (Greece)
- University of Southampton IT Innovation Centre (UK)
- ARTS Association (France)
- SportsCurve (Germany)
- Cyberlighting (Finland)

13 Appendix D: Golfing LIVE 3 user profiling questionnaire

3DLive Golf : Questionnaire Live 3

* Requirec

Informations sur votre profil

Veuillez répondre aux questions suivantes, relatives à vos données personnelles.

Âge *

Sexe *

- Homme
- Femme

Golfeur professionnel *

- Oui
- Non

Handicap *

(renseignez zéro si non golfeur)

Préférence manuelle *

- Droitier
- Gaucher

« Back   Continue »

27% completed

Powered by Google Forms

Report Abuse - Terms of Service - Additional Terms

3DLive Golf : Questionnaire Live 3

* Required

Expérience en Golf

Veuillez répondre aux questions suivantes, relatives à votre expérience avec le golf.

Combien de fois jouez vous au golf ? *

- (•) Jamais
- ( ) Moins d'une fois par an
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Plus d'une fois par semaine

Comment vous décririez-vous en tant que golfeur ? *

- (•) Pas d'expérience
- ( ) Novice
- ( ) Débutant
- ( ) Intermédiaire
- ( ) Expérimenté
- ( ) Très expérimenté

Avez-vous déjà utilisé un simulateur intérieur de golf ? *

- (•) Pas d'expérience
- ( ) Moins de 10 minutes
- ( ) Moins d'une heure
- ( ) Moins d'un jour
- ( ) Plus d'un jour

Avez-vous déjà utilisé des applications mobiles de golf ? *

- (•) Pas d'expérience
- ( ) Moins de 10 minutes
- ( ) Moins d'une heure
- ( ) Moins d'un jour
- ( ) Plus d'un jour

Comment décririez-vous votre expérience de golf la plus courante ? *

- (•) Pas d'expérience
- ( ) J'ai détesté
- ( ) Je n'ai pas vraiment aimé
- ( ) Je n'ai pas aimé cela
- ( ) J'ai aimé
- ( ) J'ai vraiment aimé
- ( ) J'ai adoré

« Back   Continue »

28% completed

Expérience en informatique et jeux vidéo

Veuillez répondre aux questions suivantes, relatives à votre expérience relative à l'informatique et aux jeux vidéo.

Combien de fois utilisez-vous un ordinateur dans le cadre de votre activité professionnelle ? *

- (•) Jamais
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Moins d'une fois par jour
- ( ) Moins d'une heure par jour
- ( ) Plus d'une heure par jour

Combien de fois utilisez-vous un ordinateur chez vous ou dans le cadre de vos loisirs ? *

- (•) Jamais
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Moins d'une fois par jour
- ( ) Moins d'une heure par jour
- ( ) Plus d'une heure par jour

Combien de fois jouez-vous aux jeux vidéo sur ordinateur ou sur console ? *

- (•) Jamais
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Moins d'une fois par jour
- ( ) Moins d'une heure par jour
- ( ) Plus d'une heure par jour

Combien de fois jouez-vous aux jeux vidéo sur smartphone ou tablette ? *

- (•) Jamais
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Moins d'une fois par jour
- ( ) Moins d'une heure par jour
- ( ) Plus d'une heure par jour

Combien de fois jouez-vous aux jeux vidéo sur ordinateur ou sur console avec d'autres personnes ? *

- (•) Jamais
- ( ) Moins d'une fois par mois
- ( ) Moins d'une fois par semaine
- ( ) Moins d'une fois par jour
- ( ) Moins d'une heure par jour
- ( ) Plus d'une heure par jour

Comment évaluez-vous votre expérience concernant l'interaction avec des environnements virtuels 3D ? *

- (•) Pas d'expérience
- ( ) Novice
- ( ) Débutant
- ( ) Intermédiaire
- ( ) Expérimenté
- ( ) Très expérimenté

Comment évaluez-vous votre expérience quant aux jeux de sport en 3D ? *

- (•) Pas d'expérience
- ( ) Novice
- ( ) Débutant
- ( ) Intermédiaire
- ( ) Expérimenté
- ( ) Très expérimenté

Comment évaluez-vous votre expérience avec des jeux basés sur la Kinect de Microsoft ? *

- (•) Pas d'expérience
- ( ) Novice
- ( ) Débutant
- ( ) Intermédiaire
- ( ) Expérimenté
- ( ) Très expérimenté

Comment décririez-vous votre expérience de jeux vidéo la plus courante *

- (•) Pas d'expérience
- ( ) J'ai détesté
- ( ) Je n'ai pas vraiment aimé
- ( ) Je n'ai pas aimé cela
- ( ) J'ai aimé
- ( ) J'ai vraiment aimé
- ( ) J'ai adoré

« Back   Continue »   35% completed

Fin des questions préliminaires

Vous avez finis la première étape.

D'ici quelques instants vous allez pouvoir participer à l'expérience 3DLive golf.

14 Appendix E: Golfing LIVE 3 QoE questionnaire

3DLive Golf : Questionnaire Live 3

* Required

Qualité de l'expérience

Questions communes aux participants intérieurs et extérieurs

Pendant les phases de tir, J'ai beaucoup interagi avec mon partenaire. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de déplacement J'ai beaucoup interagi avec mon partenaire. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de tir, J'ai apprécié discuter avec mon partenaire. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de déplacement, J'ai apprécié discuter avec mon partenaire. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de tir, j'étais connecté avec mon partenaire au point de me sentir au même endroit que lui. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de déplacement, j'étais connecté avec mon partenaire au point de me sentir au même endroit que lui. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Pendant les phases de tir, J'avais l'impression que mon partenaire jouait sur le même terrain que moi. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Durant les phases de déplacement, j'avais l'impression que mon partenaire marchait sur le même terrain que moi *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de tir, J'avais l'impression d'être dans un autre monde virtuel, partagé avec mon partenaire. *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de tir, J'avais l'impression que les mouvements de mon partenaire étaient reproduis sur son avatar *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de tir, J'avais l'impression que l'autre avatar était réellement mon partenaire. *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Je trouve que le positionnement des joueurs à l'écran était cohérent. *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Je trouve que le positionnement des balles à l'écran était cohérent. *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de déplacement, J'avais l'impression d'être dans un autre monde virtuel, partagé avec mon partenaire. *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de déplacement, J'avais l'impression que les mouvements de mon partenaire étaient reproduis sur son avatar *

1 2 3 4 5 6 7

Pas d'accord du tout ○ ○ ○ ○ ○ ○ ○ Tout à fait d'accord

Pendant les phases de déplacement, J'avais l'impression que l'autre avatar était réellement mon partenaire. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Je me concentrais pour ajuster mes swings en fonction du parcours. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

J'ai eu l'impression de pouvoir bien contrôler la puissance de mes frappes. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Je trouve que l'environnement virtuel ressemblait au vrai cours de golf. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Je trouve que les avatars étaient graphiquement réalistes. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

Je trouve que les mouvements des avatars étaient réalistes. *

	1	2	3	4	5	6	7	
Pas d'accord du tout	○	○	○	○	○	○	○	Tout à fait d'accord

« Back   Continue »

57% completed

3DLive Golf : Questionnaire Live 3

Etat Emotionnel

Quel est votre ressenti après avoir essayé la plateforme ?

Je me sens plutôt

	1	2	3	4	5	6	7	
Triste	○	○	○	○	○	○	○	Joyeux

	1	2	3	4	5	6	7	
Frustré	○	○	○	○	○	○	○	Soulagé

	1	2	3	4	5	6	7	
Indifférent	○	○	○	○	○	○	○	Surpris

	1	2	3	4	5	6	7	
Désinteressé	○	○	○	○	○	○	○	Surpris

	1	2	3	4	5	6	7	
En colère	○	○	○	○	○	○	○	Heureux

	1	2	3	4	5	6	7	
Repoussé	○	○	○	○	○	○	○	Attiré

« Back   Continue »

64% completed

3DLive Golf : Questionnaire Live 3

* Required

Afin de cibler les questions qui vont suivre en fonction du type d'expérience que vous avez vécu (intérieur ou extérieur), merci de répondre à la question suivante :

Quel type d'utilisateur étiez-vous ? *

- J'étais utilisateur en intérieur
- J'étais utilisateur en extérieur

Afin de cibler les questions qui vont suivre en fonction du type d'expérience que vous avez vécu (intérieur ou extérieur), merci de répondre à la question suivante :

Quel type d'utilisateur étiez-vous ? *

- J'étais utilisateur en intérieur
- J'étais utilisateur en extérieur

3DLive Golf : Questionnaire Live 3

Fin du questionnaire

Vous avez fini le formulaire !

Merci pour votre participation !

L'équipe 3D-LIVE

« Back Submit

100%: You made it.

Never submit passwords through Google Forms.

15 Appendix F: Jogging LIVE 3 user profiling questionnaire

User Profiling Questionnaire

PART A

All users should fill this in before starting the 3D-LIVE experience

Experimental conditions

User ID : ....

Date : ....

I am an INDOOR runner/OUTDOOR runner [please mark which type you are]

Jogging circuits (please circle the games you ran)
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20]

About you

Age : .... Sex : ☐ Male / ☐ Female

Jogging experience

How often do you go jogging?

☐ Never	☐ Less than once a year	☐ Less than once a month	☐ Less than once a week	☐ More than once a week

How would you describe yourself as a jogger?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Advanced	☐ Professional

Have you had experience of using running/jogging mobile applications?

☐ No experience	☐ Less than 10 minutes	☐ Less than 1 hour	☐ Less than 1 day	☐ More than 1 day

How would you describe your most common jogging experience?

☐ No experience	☐ I hated it	☐ I really didn't like it	☐ I didn't like it	☐ Did not like or dislike it	☐ I liked it	☐ I really liked it	☐ I loved it

1

Computer and games experience

How often do you use a computer for your professional work?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than once an hour	☐ More than one hour a day

How often do you use a computer for your home or leisure?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than once an hour	☐ More than one hour a day

How often do you play computer or tablet/mobile phone games?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than one hour a day	☐ More than one hour a day

How often do you play computer or tablet/mobile phone with others?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than one hour a day	☐ More than one hour a day

How do you rate your experience with interacting in 3D virtual environments?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

How do you rate your experience with 3D sports games?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

How do you rate your experience with Augmented Reality games?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

How would you describe your most common computer gaming experience?

☐ No experience	☐ I hated it	☐ I really didn't like it	☐ I didn't like it	☐ Did not like or dislike it	☐ I liked it	☐ I really liked it	☐ I loved it

2

16 Appendix G: Jogging LIVE 3 QoE questionnaire

User Experience Questionnaire

PART B

All users should complete this part of the questionnaire, after completing the 3D-LIVE user experience

Experimental conditions

User ID : ....

Date : ....

Jogging circuits (please circle the games you played)
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20]

Please carefully read each statement below and then mark to what extent you agree or disagree with the each statement.

About my 3D-LIVE experience

Running as a group to the mid-point

When running to the mid-point, I interacted with other joggers

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As we ran to the mid-point, I enjoyed chatting with other joggers

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

When running to the mid-point, I felt I was sharing the same running course with the other joggers.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As we ran to the mid-point, I felt connected to the other joggers.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

3

During running to the mid-point, it felt like I was in the same physical spaces as the other joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Whilst running towards the mid-point, I felt able to be supportive to the other joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During this running phase, I felt other joggers encouraged me.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Running to the end

When running to the finish, I interacted with other the joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As I ran to the finish, I enjoyed chatting with the other joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As I ran to the finish, I felt I was sharing the same running course with the other joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I felt connected to the other joggers when I was running to the finish.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During my run to the finish, it felt like I was in the same physical spaces as the other joggers.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I felt able to be supportive to the other joggers when running to the finish.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During my run to the finish, I felt others encouraged me.

	1	**2**	**3**	**4**	**5**	**6**	**7**	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

After the experience

Whilst I was using the 3D-LIVE system I felt:

	1	2	3	4	5	6	7	
Sad	○	○	○	○	○	○	○	**Happy**
Frustrated	○	○	○	○	○	○	○	**Relieved**
Indifferent	○	○	○	○	○	○	○	**Surprised**
Disinterested	○	○	○	○	○	○	○	**Interested**
Repulsed	○	○	○	○	○	○	○	**Attracted**
Upset	○	○	○	○	○	○	○	**Pleased**

User Experience Questionnaire

PART C

Outdoor users only

should complete this part of the questionnaire

User ID : ....

Date : ....

Running as a group to the mid-point

Whilst running to the mid-point, I felt my position on my 3D-LIVE app was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Running to the end

Whilst running to the finish, I felt my position on my 3D-LIVE app was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

User Experience Questionnaire

PART D

Indoor users only

should complete this part of the questionnaire.

User ID : ....

Date : ....

Running as a group to the mid-point

As we ran to the mid-point, I felt the virtual environment was graphically realistic

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Whilst running in a group, I felt the positioning of the my avatar on the screen was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Whilst to the mid-point, the positioning of other jogger's avatars on the screen was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Whilst running in the group, my avatar's movements accurately matched my physical movements

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During the run to the mid-point, other avatars movements looked realistic.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I thought the realism of the 'photo realistic avatar' was high during my run to the mid-point

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During the run to the mid-point, I got the feeling I was inside a virtual world with others.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

7

As we ran in this phase, I felt the other avatars were actually the other joggers.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Running to the end

As I ran to the finish, I felt the virtual environment was graphically realistic

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Whilst running to the finish, I felt the positioning of the my avatar on the screen was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As I ran to the finish, I felt the positioning of other jogger's avatars on the screen was consistent

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

Running to the finish, my avatar's movements accurately matched my physical movements

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During the run to the finish, other avatars movements looked realistic.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

As we ran to the finish, I felt the other avatars were actually the other joggers.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I thought the realism of the 'photo realistic avatar' was high during my run to the finish.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During the run to the finish, I got the feeling I was inside a virtual world with others.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

System Usage Questionnaire

PART E

<u>All users</u> should complete this part of the questionnaire, <u>after completing</u> the 3D-LIVE user experience

User ID : ....

Date : ....

My thoughts about the system

My feelings toward the 3D-LIVE system now are:

	1	2	3	4	5	6	7	
Bored	○	○	○	○	○	○	○	**Excited**
Indifference	○	○	○	○	○	○	○	**Challenged**
Disinterested	○	○	○	○	○	○	○	**Interested**

It was easy to enter into a 3D-LIVE jogging experience.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

It was simple to leave a 3D-LIVE jogging experience.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

This type of system would be useful for professional runners.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

This type of system would be useful when I do not have access to treadmill.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

This type of system would be useful for remotely jogging with friends.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

This type of system would be useful for just jogging with friends indoors.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

This type of system would be useful for introducing non-joggers to a running experience.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I found it easy to use the system.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I found that there were delays that interrupted my experience whilst jogging.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

I think the system I tried today is reliable.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

The End.

Thank you very much for taking part in this evaluation of the 3D-LIVE system and your patience in answering all these questions.

The 3D-LIVE TEAM.

17 Appendix H: Skiing LIVE 3 user profiling questionnaire

User Profiling Questionnaire

User ID : ....

Date : ....

I am an INDOOR skier/OUTDOOR skier [please mark which type you are]

Skiing trial (please circle your trial number)
[1] [2] [3] [4] [5] [6] [7] [8]

About you

Age : .... Sex : ☐ Male / ☐ Female

Skiing experience

[1] How often do you go skiing?

☐ Never	☐ Less than once a year	☐ Less than once a month	☐ Less than once a week	☐ More than once a week

[2] How would you describe yourself as a skier?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Advanced	☐ Professional

[3] Have you had experience of using skiing related mobile applications?

☐ No experience	☐ Less than 10 minutes	☐ Less than 1 hour	☐ Less than 1 day	☐ More than 1 day

[4] How would you describe your most common skiing experience?

☐ No experience	☐ I hated it	☐ I really didn't like it	☐ I didn't like it	☐ Did not like or dislike it	☐ I liked it	☐ I really liked it	☐ I loved it

Computer and games experience

[5] How often do you use a computer for your professional work?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than once an hour	☐ More than one hour a day

1

[6] How often do you use a computer for your home or leisure?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than once an hour	☐ More than one hour a day

[7] How often do you play computer or tablet/mobile phone games?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than one hour a day	☐ More than one hour a day

[8] How often do you play computer or tablet/mobile phone with others?

☐ Never	☐ Less than once a month	☐ Less than once a week	☐ Less than once a day	☐ Less than one hour a day	☐ More than one hour a day

[9] How do you rate your experience with interacting in 3D virtual environments?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

[10] How do you rate your experience with 3D sports games?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

[11] How do you rate your experience with Augmented Reality games?

☐ No experience	☐ Novice	☐ Beginner	☐ Intermediate	☐ Experienced	☐ Very experienced

[12] How would you describe your most common computer gaming experience?

☐ No experience	☐ I hated it	☐ I really didn't like it	☐ I didn't like it	☐ Did not like or dislike it	☐ I liked it	☐ I really liked it	☐ I loved it

2

18 Appendix I: Skiing LIVE 3 QoE questionnaire

For the purposes of brevity, only the indoor user questionnaire is presented here; the outdoor question is a subset of this questionnaire.

INDOOR User Experience Questionnaire

User ID : ....

Date : ....

Skiing trial (please circle your trial number)
[1] [2] [3] [4] [5] [6] [7] [8]

At the meeting point

[1] I was able to interact fully with other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[2] It was easy to talk with the other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[3] It felt like the other players were in the same place as me.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[4] Other skiers did not react to me during game play.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[5] I felt happy to chat to other players about the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

At the race starting point

[6] I was able to interact fully with other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[7] It was easy to talk with the other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[8] It felt like the other players were in the same place as me.

1

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[9] Other skiers did not react to me during game play.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[10] I felt happy to chat to other players about the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

During the race

[11] I was able to interact fully with other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[12] It was easy to talk with the other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[13] It felt like the other players were in the same place as me.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[14] Other skiers did not react to me during game play.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[15] I felt happy to chat to other players about the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

At the end of the race

[16] I was able to interact fully with other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[17] It was easy to talk with the other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[18] It felt like the other players were in the same place as me.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[19] Other skiers did not react to me during game play.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[20] I felt happy to chat to other players about the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

After the experience

[21] During the game my physical movements turned into realistic skiing actions in the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[22] I had full control over the speed and direction of my avatar on the slope.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[23] The appearance of the 'photo realistic' avatar was highly realistic.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[24] During the game I forgot that I was playing a game indoors.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[25] My avatar's movements matched my own body movements correctly.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[26] During the game it felt like the avatar was really me.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[26a] Overall, I felt connected with the other players in the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[27] During the game the 3D-LIVE made me want to connect with the other players.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[28] The appearance of avatars was realistic in the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[29] Whilst I was using the 3D-LIVE system I felt:

	1	2	3	4	5	6	7	
Sorrow	○	○	○	○	○	○	○	Joy
Frustrated	○	○	○	○	○	○	○	Relieved
Distracted	○	○	○	○	○	○	○	Focused on the game
Indifferent	○	○	○	○	○	○	○	Surprised
Disinterested	○	○	○	○	○	○	○	Interested
Angry	○	○	○	○	○	○	○	Happy
Bored	○	○	○	○	○	○	○	Full engaged
Repulsed	○	○	○	○	○	○	○	Attracted

[30] Using the 3D-LIVE equipment disrupted my experience of the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[31] The virtual environment looked like a realistic representation of a skiing slope.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[32] Avatar body movement in the game was realistic.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[33] While playing the game, I lost the feeling that time was passing.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[34] I interacted with the game to improve my performance during the race.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

4

My thoughts about the system

[35] My feelings toward the 3D-LIVE system now are:

	1	2	3	4	5	6	7	
Bored	○	○	○	○	○	○	○	Excited
Indifference	○	○	○	○	○	○	○	Challenged
Disinterested	○	○	○	○	○	○	○	Interested

[36] It was easy to enter into a 3D-LIVE skiing experience.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[37] It was easy to leave a 3D-LIVE skiing experience.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[38] This type of system would be useful for professional skiers.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[39] This type of system would be useful for remotely skiing with friends.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[40] I would use the 3D-LIVE system in the future.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[41] This type of system would be useful for just having fun.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[42] I found it easy to use the system.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[43] I think the system I tried today behaved in a consistent way.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	Totally agree

[44] I found that there were delays that interrupted my experience during the game.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

[45] I think the system I tried today was reliable.

	1	2	3	4	5	6	7	
Not agree at all	○	○	○	○	○	○	○	**Totally agree**

The End.

Thank you very much for taking part in this evaluation of the 3D-LIVE system and your patience in answering all these questions.

The 3D-LIVE TEAM.

19 Appendix J: Post LIVE 3 traceability matrix

ID	Feedbacks	Requirement	addressed for	Action taken	Evaluation
Requirements extracted from Co-Creation workshops					
R0-1	Voice communications very important, like a phone call. A common language must be spoken	Integrate a voice communications system transparent to users	LIVE3	ARTS worked on the improvement of The Voice Chat Unity3D plugin, trying to optimise the compression/decompression and transmission in background using Unity3D. Finally this plugin has been removed for the Golf and Ski scenarios as no performances improvements were reached. The use of the external Voice Client Mumble has been chosen. Easy to setup and very efficient.	Mumble voice client validated for all the scenarios. Everything went well
R0-2	Kinect skeleton quality is poor occluded areas for indoor users	Enhance the quality of the skeleton in occluded areas for indoor users	LIVE1	Developed a skeleton merging algorithm from multiple Kinects. Published a paper in a conference. Integrated the Skeleton Merging algorithm from multiple Kinects in 3DLive Capturer.	Skeleton tracking is improved in occluded cases. Furthermore, the performance of the module was improved due to addressing R1-3
R0-3	Calibration only once, and quick if entertainment purpose	Calibration time must be < 1s and easy to users	LIVE2	CERTH has put in place an automatic calibration process in the Kinect capturer. Once the user is detected in T-Pose, the capturer calibrates the skeleton and add a calibration information to skeleton message queried by the 3Dlive applications.	Calibration of Kinect sensors automatically detected when user is in T-Pose

R0-4	Low latency in voice : most important data for users, communications must be like a phone call	Voice quality : low latency < 500ms	LIVE3	Same as R0-1	Mumble voice client validated for all the scenarios. Everything went well
R0-5	Predefined animations as an outdoor player satisfaying	Integrate predefined animations for the outdoor player (three scenarios)	LIVE1	A set of Motion Capture data has been recorded by CERTH for the three scenarios, including animations for: walk, run, rest pose, golf swing, ski acceleration, ski turns, ski normal pose. A reader was created in order to keep a uniform way of animating the avatars whether they use live skeleton animation or pre-recorded animation data.	The animations are not very good. But they are sufficient to understand what the outdoor avatars are actually doing
R0-6	Graphics should be detailed.The virtual golf course must be realist, and look like the real one. Golfers must be able to recognize each part of the field.	Graphics: 3D environments realist enough to be recognizable	LIVE1	Jogging Scenario: A 3Dmodel of the city centre of Oulu was already available with enough details for users to recognize where they are in the streets. Golf scenario: A basic topology of the Laval golf course (Hole n°1) was available, materials, trees, grass, water and simple 3Dmodels were added to make the Unity3D terrain more representative of the reality. Skiing scenario: Based on a high resolution mesh provided by IT Innovation, ARTS	The main topology of the course and important buildings/details have been modelled. Enough details were generated

				created the Unity3D terrain of the Hopsilift ski slope in Schladming. Simple trees and 3D elements have been created in order to make the model representative of the reality.	
R0-7	The weather must be the same for outdoors and indoors. However in a solo mode, the weather should be configurable	Module: Weather reconstruction system required	LIVE1	A first version of the ERS has been developed by IT Innov. It allows the collection of Open Weather Map data based on GPS locations inputs, on a RabbitMQ server. On the rendering side (both Unity3D and RealXtend) weather effects in the virtual environment have been integrated by Cyber and ARTS.	The ERS is able to propose a full representation of the weather. The Game engine is capable yet of reconstructing virtually the basic weather effects (sun, temp, wind, cloud coverage, rain)
R0-8	No text, prefer pics and graphics	Graphics: feedbacks with graphical elements more than text	LIVE2	ARTS worked with a graphics designer to create the overall 3DLive GUI based on our storyboards. The different GUI elements for the required data to display have been created, and integrated in the applications.	The 3DLive UI was able to display feedbacks with graphical elements rather than text.
R0-9	Graphical content consistent : avatars	Module: Human Reconstruction	LIVE2		Human Reconstruction was integrated successfully in the app.

	realistic = all game environment realistic	with high quality required			
R0-10	A race / pursuit is required by the users	Gameplay: Race between the users, gamification to increase sense of immersion	LIVE3	ARTS, IT-Innovation and CERTH worked on the integration of a complete racing gameplay and new Activity Recognition features to get engaged in the race. The flow is the following: The indoor users can practice and race with or without gates while the outdoor is taking the lift. A countdown is triggered; the indoor users have the ability to accelerate by pushing on their virtual ski poles. Once they are hurtling down the slope, the capturer tells the app how much the indoor user is bending. This lower down the drag coefficient of the virtual skier to increase his speed. Consequently indoor users have the opportunity to race down from 70km/h to 110km/h depending on their actions. During the race each user can see the position of other players, the chrono, their speed and the delay compared to the first in race when crossing checkpoints gates. At the end a scores panel pops up to display the times of all the players and the best times of aggregated races. When the outdoor user is ready to race,	The Ski application provides now a rich gameplay with feedbacks about other users. Users are free to race straight downhill, to have a slalom or a free run. The competition spirit is very clear for both sides of the scenario and the users wanted to race each time. Adding gates for a slalom or a simple race downhill was a really good thing, as he balanced the difficulty of the game indoors depending on the outdoor slope conditions (ridges, quality of snow in the afternoon)

				indoors is automatically teleported at the starting gate, the outdoor user sees the virtual gate through his Heads Up Display and reaches the indoor racers. He can trigger the start of a new race with his wrist controller once he is ready. During the race, he can see the mountain view with pins of the players. At the end he can even see the podium with avatars animated live on it.	
R0-11	Information of speed is important	Gameplay: Display speed information	LIVE3	Skiing scenario: ARTS worked much on the physics of the indoor skier. New algorithms have been set up based on the literature to obtain a realistic physics on the virtual slope. Tests have been performed and outdoor/indoor users got similar race times while going full speed on the World Cup slope.	Speed consistent with the activity of the players in Skiing and Jogging Scenario

R0-12	Comparative Stats must be displayed after a game	Gameplay: Comparative Performance feedbacks post experience	LIVE3	Jogging Scenario: Scaling of the speed indoors and outdoors worked very well after few calibration rounds. People matched their running speed with each other fairly easily.	At the end of a game, the users for all scenarios are able to compare their statistics of the race
R0-13	Face realism important on 3D representation of indoor users	Improve Microsoft Kinect sensor placement	LIVE1	One Microsoft Kinect sensor placed horizontally and closer to the user front in order to improve face capturing	The face capturing quality showed a significant improvement when compared to initial trials.
R0-14	Users free to choose position to start from	Gameplay: ability to define starting points in the app	LIVE1	Before starting a game, the position of the starting point and the position of the hole (which changes over time) must be configured. In the settings of the outdoor app we implemented a feature allowing a user to record these positions based on GPS signal. This position will be automatically shared with all connected players in the game, to update their scenario and the position of the appropriate 3Dmodels. For the position of the hole, a dynamic hole has been created based on enabling/disabling mesh colliders + custom occlusion shader on the main virtual course.	The option allows users to define the pin and starting position on the real golf course before starting the game

R0-15	Include rules for "lost balls" (golf)	Gameplay: Implement a consistent scenario in case of lost ball	LIVE3	In the Golfing scenario, indoor golfers can strike the ball out of virtual boundaries. We included a new game phase in order to virtually consider the ball as "lost" and replace it at the proper position based on golfers' requirements. On the other side, in LIVE 2 we learnt that outdoor golfers can just lose their ball in the rough.. There is now a button on the tablet to tell the app a user lost his ball. Consequently the game will consider that users must start again from the previous position.	Lots of new game phases implemented for the golf scenario including the "lost balls" feature, which is used sometimes, so it is was really necessary
R0-16	Include stats 'number of strikes, length and 3D trajectories'	Gameplay: display the 3D trajectories, length and number of strikes	LIVE3	ARTS worked on the Activity Recognition. Golf strikes activity recognition has been reviewed in order be used in every direction outdoors. Tests on the practice course were performed in order to assess and adjust some parameters of our model in an empirical way.	No more problems with carbon shafts. But still some problems of drifting after strong strikes. The EXEL-S1 sensors seem not appropriate for the golf purpose
R0-17	Device: sporting equipment in a fitness club	Input: A sporting equipment from fitness club is required	LIVE1	A first version of the Pro ski simulator controls has been implemented by ARTS thanks to a setup using Arduino board and standard IMU sensor. The data is sent to the port COM via Bluetooth or USB. Then the orientation of the sensor is read to get the range of the turns	The inertial sensor attached to the ski simulator allows us to control the direction of the skier on the slope in a natural way.

R0-18	The outdoor must not wait for others, once he is ready the game must start when he wants	Gameplay: Outdoor triggers the start of the shared experience	LIVE3	ARTS and IT-Innov worked on the integration of the Recon Snow 2 goggles. In the 3DLive Smartphone application, ARTS integrated more game phases to identify better the exact status of the game for indoors and outdoors separately. In addition to the game phases, GPS areas have been defined in order to trigger automatically events to display in the HUD. Based on our specifications, IT Innov developed the content in the HUD including pins animation, avatar representation, and scores management. Communications between phone and Glasses are handled through UDP sockets communications. The wrist controller of the goggles can send instructions to the phone in order to start the race, pair or un-pair from the phone for instance.	The Recon Snow2 goggles are now integrated to provide the outdoor user an immersive experience with his remote friends. He has also the ability to start the race when ready at the top with the wrist controller paired to the goggles
R0-19	simple gaming devices (like WiiBB) not appropriate for sports purpose, but for gaming only	Input: A wii fit board controller must be integrated for gaming purpose	LIVE1	The Wii Fit board has been integrated by ARTS. The distribution of the weight of the user was retrieved by the GlovePie middleware then sent locally through OpenSoundControl (UDP) messages to the ski application. The weight distribution allows the user to control his skier like in a video game.	The weight balance allows users to control the direction of the indoor skier. The control is still a bit hard.

R0-20	A HMD must be considered for indoor users (lower price with interesting immersion)	Rendering: different visualisation devices are required. Users need lower prices with highest sense of immersion	LIVE3	The 3Dlive platform has been designed to be able to connect various external VR devices. ARTS used MiddleVR middleware to configure the indoor ski application to Oculus Rift and Clarté SAS3+ CAVE. A specific 3D User Interface handler has been designed in order to manage graphical UIs with 3D models instead of overlay that cannot be rendered in those immersive devices.	HMDs and CAVEs are now part of the 3D-LIVE system, which can be deployed on different devices. They provide a great User Experience and satisfaction. The sense of immersion was assessed to be even higher in the HMDs with the small user group which tested both solutions.
R0-21	The outdoor mask must not be dangerous for the activity. AR Glasses very important to rationalise the point of wearing sensors	Rendering: Outdoor visualisation required, but AR not appriopriate	LIVE3	See R0-16	The Recon Snow2 goggles are now integrated to provide the outdoor user an immersive experience with his remote friends. He has also the ability to start the race when ready at the top with the wrist controller paired to the goggles
R0-22	The outdoor mask must be protected from moisture, falls and weather conditions	Safety: mask but be protected	LIVE3		The Recon Snow2 goggles is a product on the market, including moisture protection, comfort and safety regulations

R0-23	The indoor user must feel the sensation of steepness and speed	Rendering: The immersion must be high enough to let the users feel the steepness	LIVE3	ARTS performed a work on shaders, camera frustum distortion and visual effects but the result was not satisfying with simple 2D screens. The integration of immersive rendering devices (CAVE and HMD), created the needed feeling of speed and steepness of the ski slope.	On simple displays, the feeling of speed is not great. Even visual effects did not improve much the feeling of speed for the users. But the addition of immersive rendering devices like HMDs and CAVEs and sound feedbacks increased much the feeling of speed and immersion on the actual slope. When the head of a user is looking down, he can now feel the steepness.
R0-24	Predefined routes are necessary	Gameplay: Predefined routes for the jogging	LIVE1		The indoor jogger automatically follows a predefined route
R0-25	Include a way to socialize after a game	Gameplay: Comparative Performance feedbacks post experience	LIVE3	Ski scenario: We included race performance handler, in order to save the different race positions and times of races done during a game. Indoor and outdoor users can now see the race times of other racers. The outdoor user can even see a podium with animated avatars on it, thanks to the communications between the Smartphone and the Recon Snow2 goggles Golf scenario: All shots, distances and performances are saved during a game, Once the ball is in the hole, the two players have access to a summary of their performance: who did the best/worst	All the users, for the three scenarios have now access to the performance feedbacks of other players after a game. Users were satisfied by the information displayed.

				strike, how many times their ball was selected..etc.	
R0-26	Sensory data is important (heart rate)	Input: Heart rate and other sensory data required for the jogging activity	LIVE3	Bluetooth Low Energy HR protocol was implemented to the outdoor application and tested using Viiiiva HRM accessory successfully. IMU sensors provided by Sports Curve were implemented partially to outdoor jogger application but late arrival of the sensors just before LIVE3 testing did not allow working implementation of the jogger avatar animation.	
R0-27	Runners should be close to one another even if they run at different speeds	Gameplay: The indoor player speed must be adjusted	LIVE3	No action taken. Adjustment of the indoor jogger speed outside of the treadmill would have undermined the purpose of Kinect speed estimation.	

R0-28	Ability to replay shots	Gameplay: ability to replay shots	LIVE3	No action taken, as replay in Golfing scenario was important only for a training purpose	Not integrated. But no user finally asked for that during the live tests
R0-29	Users should not be able to talk to each other during strikes	Gameplay: disable voice comms during shots	LIVE2	We added a feature in order to force mute the different players during strikes while a user requires some focus and preparation during his strike.	Outdoors were muted when indoors were taking strikes. Indoors were muted while outdoors were taking strikes
R0-30	Outdoor can ski down without indoors	Gameplay: outdoor user able to run without indoors	LIVE3	A mode solo is available for both indoors or outdoors if they want to run	Tested internally. Not experimented with users because no interest in our research purpose.
R0-31	A replay must be available for the players. Ghost runner from previous run through AR glasses	Gameplay: A replay must be available for users	LIVE3	During the ski race, the locations of all the players are stored in order to be replayed at the end. ARTS included this replay only on a 2D map considering the effort required for a 3D replay that would not add great value for this game (save positions + animations of avatars and replay it.)	A replay for the skiing scenario has been integrated. Finally users don't care and don't even look at it. They want to go at the top faster to take a revenge on the next race.
R0-32	Zero configuration on startup	Gameplay: Ability to start and go without changing settings	LIVE3		The settings were well configured in the LIVE3, decreasing considerably the waiting time for users to start a game

R0-33	Motion sensors only for training purpose, else too much disturbing.	Human Motion sensors accuracy very high for training purpose, Accuracy not needed for gaming purpose	LIVE3	ARTS integrated 4 IMU sensors (EXEL S3) in the 3D-LIVE platform. We created a new motion handler in order to perform avatar animation on a part of the body. One sensor was attached to the Torso, one to the head, one to the upper arm and the last one on the arm. A new model of animation has been created in order to fuse predefined animations with live IMU animations, in the local references of the Torso. It was working well, but the process of attaching the sensor needs much accuracy, sensors can move. So for sure they would have moved during a race. An existing MoCap suit would be more convenient here.	Investigation has been carried on. 4 sensors on the body allowing local bones animations with the torso as a reference, has been tested. The problem is attaching the sensors on the body requires much accuracy to get consistent animation during the whole race. To do so, suit with sensors already attached (xSense/Heddokko) would be necessary.
R0-34	Voice Comms optional	Voice: The component must be easily enabled/disabled by the user	LIVE2		The setting to enable/disable voice is straightforward to use
R0-35	Option to be able to see others (birds eye view, map with markers)	Gameplay: Birds eye view required	LIVE3	A key on a keyboard can simply switch between views.	Key can switch the view into first/third person view or bird's eye view
Requirements extracted from LIVE 1					

R1-1	Poor Outdoor UX Skiing LIVE 1	Create the user engagement of outdoor users in the game	LIVE3	IT Innov and ARTS reshaped the skiing scenario with the support of Schladming 2030. IT Innovation provided a new high accuracy 3D model of the slope, and several 3D models of the buildings at the bottom of the Planai station. ARTS integrated this model in the rendering engine and added the required content to feel on the real slope: trees around, missing buildings, lift. In addition to that a shader displaying procedural snow on this new terrain was used. See responses for the R0-9 and R0-19 for more information on the gameplay and Heads Up Display	The race mode is happening on the World Cup black slope of Schladming. The new 3D model was created, the physics to control skier has been totally reviewed for this purpose. Gamification and sense of competition is important now. The HUD allows even outdoor users to "give it all to win the race".
R1-2	The movements of the users where mapped in reverse to avatars' movements. E.g. User's left hand movements were mapped to avatar's right hand movements.	Map the user's movement to avatar's movement appropriately for left and right hand/feet	LIVE2	Skeleton mirroring support was added in 3DLive Capturer	Avatars' movements correctly resemble the movements of the users

R1-3	It is difficult for the users to improve their Ski activity score.	The ski activity evaluation algorithm should map scores in a more natural way	LIVE2	The ski activity recognition & evaluation algorithm was reviewed and updated to better map users' activities in to the score interval [0.0-1.0]	Users find it easier to adapt their movements to the evaluation mechanism and improve their scores
R1-4	Poor voice driven voice communications in Golf and Ski scenarios	Create the user verbal engagement with one another	LIVE3	See R0-1 action taken	Mumble voice client validated for all the scenarios. Everything went well
R1-5	Unexpected avatar postures/actions	Guarantee correct avatar animations of remote players	LIVE3	After reviewing again the skeleton acquisition and skeleton merging algorithm, it was observed that at certain circumstances OpenNI would falsely detect non-existent users in the background of the capture site and the skeleton merging algorithm would try to fuse all the skeletons together. Solution was provided by adding filtering to remove non-existent, miss-detected user skeletons from OpenNI.	No more complain about weird avatar animation

R1-6	Incorrect response to physical efforts in Jogging LIVE 1	Make consistent the physical action of runners with virtual avatar motion	LIVE3	See R2-2, R2-10	For outdoor avatar motion tracking only GPS location was used therefore it was more of an approximation of the real current location, but combining this data with predefined idle, walking and running animations with speed interpolation, indoor joggers perceived the outdoor jogger avatar to be moving really smoothly and realistically.
R1-7	Not enough information of the game status	Integrate all the required information for the users	LIVE3		Users are now able to follow their activity during the game. In golf, they can have all required information about their shots and performances. In Jogging the speed and the overall performance of the activity is made available, with advices to users. In Ski, the speed, race chrono and delay compared to the faster are made available for instance, keeping our users focused on the game objectives
R1-8	Software crashes sometimes, but the game status is lost if tentative reconnection	Integrate a game content saver in case of network failure/disconnection/crash of the app in order to reconnect to the game and keep the overall	LIVE2 and LIVE3	The work has been pursued on the server and client side in order to make the re-connection more robust and retrieve the overall game status of all the connected/disconnected players.	Validated in LIVE 2 and made more robust for LIVE 3. Rare disconnections and re-connections went well at different locations in the game. Users did not complain about it.

		progression			
R1-9	Bluetooth connectivity problem while using IMU sensors and bluetooth headset at the same time	Allow a headset to work in parallel with bluetooth IMU sensors	LIVE2	The wireless headphones have been removed from the deployment setup. A wired headphone has been selected in order to let the IMU sensors work without disconnecting every two minutes.	The Wired headset and the IMU sensors worked concurrently. Users were not disturbed by using a wired headphones
Requirements extracted from LIVE 2					
R2-1	Integrate a HUD for outdoor skiers	Integrate a HUD for outdoor skiers	LIVE3	See R0-19	The Recon Ski goggles (Snow2) was integrated, allowing users to see avatars, race positions, performances of players and even the virtual mountain. This UX was really satisfactory for outdoor users
R2-2	Improve skeleton capturing quality and motion mapping	Improve skeleton capturing quality and motion mapping	1	Replaced OpenNI with Microsoft Kinect SDK in 3DLive Capturer. Additionally. developed skeleton filters. This allows smoother animations and more natural postures, even when the user is not properly facing the Kinect (hands in the back for instance). This also allows us to include robust Head tracking to improve the immersion while using HMDs.	The animation quality of the avatars was substantially improved. Users reported accurate animation of the avatars according to their movements

R2-3	The jogging activity evaluation algorithm should map scores in a more natural way. Speed recognition should be improved.	The jogging activity evaluation algorithm should map scores in a more natural way. Speed recognition should be improved.	1	Reviewed and updated the Jogging evaluation algorithm. Additionally, added support in 3DLive Capturer for Kinect v2.0 for improved body tracking and thus superior activity recognition results.	The users found the updated evaluation algorithm robust. They reported ease of adaptation of their movements in order to improve their score. Jogging speed estimation also atmosphere) covered by Open Weather Map datao way to improve this part of the Golfing scenario in Laval, not covered by Open Weather Map data.dramatically improved.
R2-4	Race on a challenging slope like World Cup slopes	Race on a challenging slope like World Cup slopes	LIVE3	See R1-1	The new slope has been integrated. A raw model from the GISS in Austria was provided and transformed into a Unity3D terrain. Trees, buildings and necessary details in the environment were modelled to provide enough realism for the Schladming users
R2-5	EOS service silent or not used	EOS service silent or not used	LIVE3		EOS not used in LIVE 3 Ski
R2-6	Avoid unexpected app exit	Avoid unexpected app exit	LIVE3	The Unity3D java activity has been updated in order to force native functions not to happen when users touch the return button on Android. Moreover a case has been attached to the Smartphone to solve the problem of "pressing the Home button"	A security has been implemented to avoid click on "return" button, then a protection case was used to avoid clicking on the "home" button. It worked well, we did not record any other disconnection/exit issue.
R2-7	ERS to match the local weather of the golf course	ERS to match the local weather of the golf course	LIVE 2		No way to improve this part of the Golfing scenario in Laval, there is not sufficient data resolution (with specific reference to low-level

					atmosphere) covered by Open Weather Map data
R2-8	Avoid inconsistencies and misdetections of the shots outdoors	Avoid inconsistencies and misdetections of the shots outdoors	LIVE3	Same as R0-14	No way to improve this part of the Golfing scenario in Laval, there is not sufficient data resolution (with specific reference to low-level atmosphere) covered by Open Weather Map data
R2-9	The Overall setup must be easy and quick	The Overall setup must be easy and quick	LIVE3		The deployment configuration has been decided and pre-configured in the apps. A simple start and GO allowed users to join the game without waiting time
R2-10	Voice latency must be very low, and not disturb the framerate of the apps	Voice latency must be very low, and not disturb the framerate of the apps	LIVE3	See R0-1	Mumble was finally used, as we did not manage to implement background tasks Unity3D to handle voice compression and transmission on multiple platforms. Mumble was a good option, it is stable, efficient and do not disturb the game at all. We recovered a high framerate in our apps.
R2-11	Make a clear 2D map of the golf course for the golfers to understand where their balls are on the course.	Make a clear 2D map of the golf course for the golfers to understand where their balls are on the course.	LIVE3	The map view was updated by ARTS, and rotated 90°	The users did not complain anymore and understood easily where their balls were on the course, by reading this 2D map.

R2-12	Harmonise the 3D reconstruction and activity recognition/speed estimation module.	Harmonise the 3D reconstruction and activity recognition/speed estimation module.	LIVE3	The capture frame-rates between the trained model of the activity recognition module and the actual subject in-game were inconsistent when 3d reconstruction was enabled. Make them consistent. When 3d reconstruction was enabled, capturing frame rates would drop to nearly ~12 fps instead of ~30fps. Moving the reconstruction process in a separate thread enabled the skeleton capturing to be performed in 30fps and be consistent with the activity recognition trained model.	The speed estimation worked flawlessly in Jogging LIVE 3
R2-13	Minimize delays of the 3d reconstructed user's transmission to a level that allows real-time interaction	Minimize delays of the 3d reconstructed user's transmission to a level that allows real-time interaction	LIVE3	In this typical issue of a producer-consumer problem where the producer produces packets at higher rates than the consumer can consume, there was a need to update the 3D Reconstruction Network receiver to use a RabbitMQ queue with network characteristics suitable for real-time tele-immersion. Thus, 3D Reconstruction Network receiver was updated to use a RabbitMQ queue that drops all received frames but the last one.	No more delays were reported from users during LIVE 3 experiments