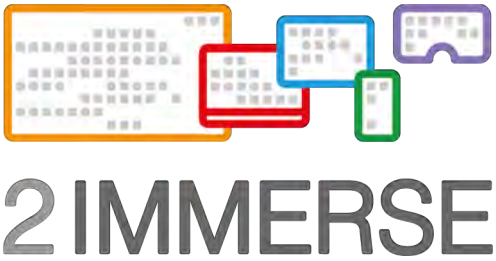
ICT-687655

Delivering Single and Multi-Screen Content Services for Immersive, Customised and Shared Experiences in Homes and Social Spaces



D4.6 Football trial evaluation results

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Abstract

While traditional live-broadcasting is typically comprised of a handful of well-defined workflows, these become insufficient when targeting at multiple screens and interactive companion devices on the viewer side. In this deliverable, we describe the football trial from the 2-IMMERSE project. This trial included the development of an end-to-end system enabling immersive and interactive experiences using an object-based broadcasting approach. We detail the deployment of this system during the live broadcast of the FA Cup Final at Wembley Stadium in London in May 2018. We also describe the trials and interviews we ran, the infrastructure we used, the final software developed for controlling and rendering on-screen graphics and the system for generating and configuring the live broadcast-objects. During this process, we learned about the workflows inside an OB truck during live productions through an ethnographic study and the challenges involved in running an object-based broadcast over the Internet which we discuss alongside other gained insights

Target audience

Please list here the targeted audience of this document (e.g. general public, highly experts in ..., etc.), and the pre-requisites expected from the readers.

Impressum

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Executive Summary

This document describes the football trial, as deployed during the FA Cup final at Wembley stadium in London in May 2018. The 2-IMMERSE team deployed there the platform and the production tools, using an OB-truck at the stadium, achieving a live object-based broadcast. This deliverable details the path towards such successful event. More information about the technology can be found in deliverables D2.4 and D2.5, and about the design of the experience and the production tools in deliverables D3.3 and D3.4. The experience reported in this deliverable (home and Fan Zone) has been showcased at the International Broadcasting Convention 2018 in Amsterdam, in a large booth including the other experiences created during the project.

A summary of this deliverable has been accepted for presentation as a Case Study at the ACM CHI Conference on Human Factors in Computing Systems 2019. ACM CHI the premier international conference of Human-Computer Interaction and will take place in Glasgow from 4th to 9th May 2018.

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Table of contents

1 Introduction

Live sport events are at the core of the television industry, since they bring the viewers close to the experience and enable them to enjoy the excitement of the event. The liveness is essential and irreplaceable by time-shifted on-demand viewing such as on Netflix [9]. However, due to the unpredictable characteristics of a live sport event, this is challenging for the production team, also because the event does not take place in a studio. Live outside broadcasts are a world of well-defined workflows to deal with time-critical tasks. The roles inside an outside broadcast (OB) truck at a live sport event are divided by task, to capture the event while minimizing delays and mistakes. Therefore, it is important that any software designed to supplement the workflow in an OB truck should be easy to operate, facilitate the collaboration within the production team and guarantee timely delivery of the live broadcast.

Figure 1: Timeline of the deployment of our end-to-end platform

This deliverable reports the development and successful deployment of an end-to-end platform for interactive, immersive broadcast at a live sports event. In particular, we detail the requirement gathering phase, the aspects of the system used during the broadcast, including a graphics compositing application, a so-called Live Triggering tool for inserting broadcast objects into live streams, the camera setup, real-time encoding of video feeds and content distribution over the Internet. We show the path from a rough first prototype to a complete multi-user platform with hardware integration. Finally, we also present a series of trials and experiments that were completed along the way, culminating the final deployment of the system at the FA Cup final at Wembley stadium in London in May 2018. There, the platform was used to support a test-broadcast of the football match, delivering the experience to a number of viewers at their homes. Figure 1 shows the timeline until the football match, including a number of subsequent technical, feasibility, and user studies.

At a big sports event such as this, an Outside Broadcasting (OB) truck is the most common unit for live broadcasting. With its mobility, OB trucks can access any location and work as a drive-in temporary production control center during live transmission, providing complete video and audio facilities (Figure 2). An OB truck typically has a wall of monitors shared by all the staff in the truck. A video production switcher controlled by the director, audio mixer, a team in charge of recording and playback decks, and a team responsible for live graphics and so on. It enables the production team to bring the TV audience an authentic visual representation of an event as it is happening [10]. OB trucks vary in sizes depending on the scale of coverage and the nature of the event. For a sport event, the coverage includes dozens of stationary cameras, a couple of handheld cameras, cameras on motorcycles to capture the main athletes and one or two helicopters with cameras to shoot the long-shot of the scene [7, 10]. Today, the production team on OB trucks orchestrates smoothly to deliver the same linear live program to all kinds TV screens. The team typically follows a pre-scripted running order document that defines in detail where graphics, visual sources and sound come from and when they should be on-air [7].

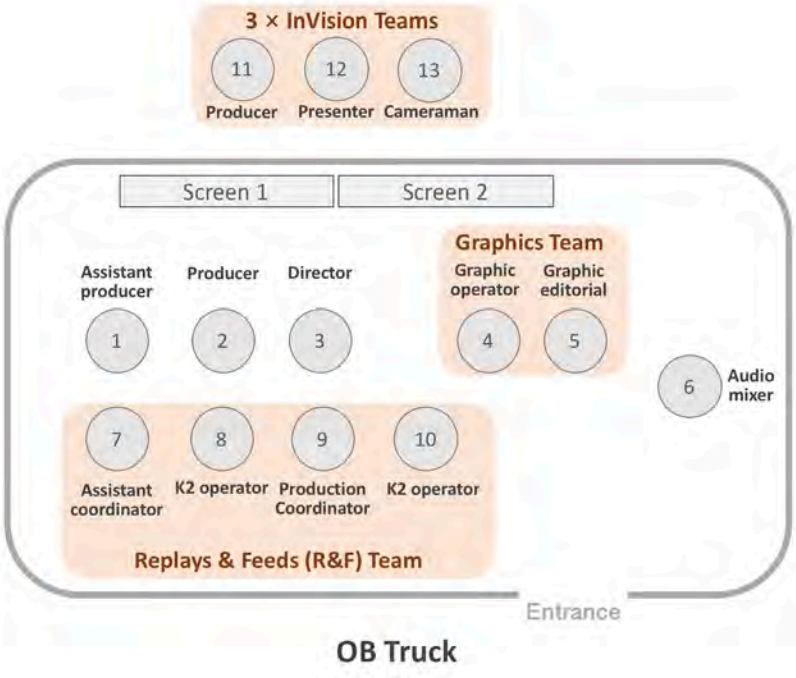


Figure 2: Layout of a typical OB truck used at a live sporting event

As companion screens (e.g. smartphones and tablets) continue to be integrated into standard television, a challenge the production team facing is to tailor the content of the TV program so that it works for multi-screen environments as though it had been uniquely created for them. Content on multi-screens is customizable to provide viewers extra flexibility and immersion when consuming the content, thus enabling interactive and immersive TV experiences [2, 4]. However, given the current workload of the live broadcasting on OB trucks, it is difficult to deliver additional versions of the program to multiple screens. New technologies are required for this purpose [1, 7]. One such technology is object-based broadcasting (OBB). It allows the content of a TV program to adapt to the requirements of different viewers on multiple screens, without requiring the production team to separately produce different versions of the program. The object, here, refers to different media assets or content objects that are used to make a TV program [1]. The OBB approach involves breaking down a program into separate objects, typically graphics, audio, video, background music, dialogues, subtitles, sound/visual effects, etc., and including metadata to describe how these objects can be assembled on multiple screens. It enables the creation of a flexible, personalized, and responsive program without increasing the

production workload [1, 6]. A rough layout of the production process using our OBB system can be seen in Figure 3 and the team of 2-IMMERSE in action at Wembley can be seen in Figure 4.

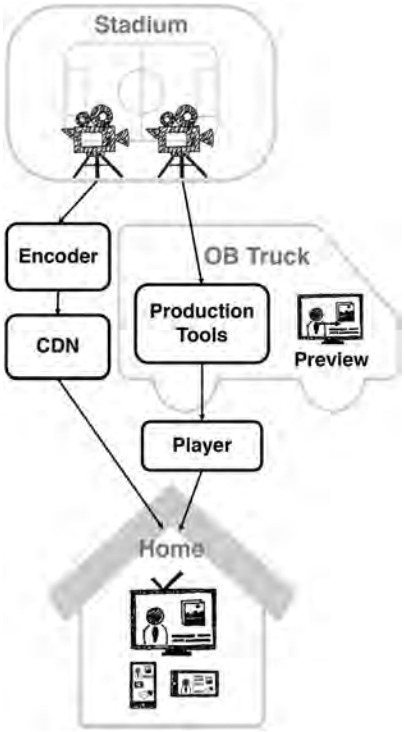


Figure 3: Production process for a live broadcast with our production platform

Figure 4: The setup of the system in the OB truck at the stadium

This deliverable is divided into three sections, chronologically ordered, from the preparation phase (section 2), the actual deployment of the system during the FA Cup Final (Section 3) and the results in the form of implications for the involved parties (Section 4).

2 Preparation

Previously (see deliverables D3.3 and D2.4 for example), we have reported successful groundwork for the design and development of a novel object-based broadcasting platform [6–8]. Our next objective was its deployment during a live event like the FA Cup Final 2018 in Wembley. To better understand the challenges of delivering such a trial at a live football match broadcast, the authors negotiated (via BT Sport) to allow observation for better understanding of the current workflow involved at an OB truck. In particular, the following events were observed (Figure 5):

- FA Community Shield match at Wembley Stadium on Sunday 6th August 2017, where access was granted only to one match truck. This event provided us with an overview of the director's role in creating the broadcast mix of video, graphics and commentary narrative for the match;
- Women's Super League match at Kingsmeadow Stadium on Thursday 1st February 2018, where access was granted to observe and record inside the OB truck. A number of GoPro cameras were used to capture the pre-broadcast preparation and live broadcast activity within the main gallery of the truck. These videos were composited into a synchronized quad view video along with the broadcast output.

Figure 5: Ethnographic study at the OB truck: Wembley Stadium (top) and Kingsmeadow Stadium (bottom), UK

The capacity afforded by Wembley Stadium in terms of connectivity, as well as physical gantry and production space, made it the preferred option as an event venue. In addition to the more ethnographic

observations detailed above, the research team, working closely with the Chief Engineer and production team at BT Sport, was allowed to run live tests during two matches at Wembley on 22nd April 2018 (FA Cup Semi-Final) and on 12th May 2018 (National League Play-Off Final).

Such observations and tests resulted in a number of requirements, anticipating operational and technological risks. Such requirements included, for example, the creation of a number of documents such as the call sheet and the team sheet (for pre-populating the graphics with the correct player names one hour before the beginning of the match). The requirements covered as well technological aspects, such as the pre-production of the assets, the development of the infrastructure to be deployed at the venue and in the cloud and the access to various data channels such as the clean video data feeds. Finally, there were other operational guidelines for, for example, granting access to the researchers or collocating our mini OB truck in the OB Compound with the other broadcasters. The following subsections will detail the different preparation steps before the official match day.

2.1 Ethnographic Studies

The first observational study was at the FA Community Shield match between Chelsea FC and Arsenal FC at Wembley Stadium on Sunday 6th August 2017. Access was only granted to Timeline's UHD1 match truck, providing an overview of the Match Directors role in creating the broadcast mix of video, graphics and commentary narrative for the match. Figure 5 (top) shows the Match Truck main gallery with the Match Director and VM (Vision Mixer) producing the FA Community Shield 2017.

A number of particular insights were gained into the match director's:

- Occasional 'direction' of the match camera operators at his disposal to capture a specific shot he required, while predominately allowing them to cover the match in pre-agreed format
- Relationship with his VM (Vision Mixer) to create the final broadcast mix of live and EVS replay content
- Vocal instructions via the production audio link to the graphics operators (located in a separate truck) to trigger, animate and remove Match GFX (graphics) during the match in sync with video or commentary

A second more focused observation of a live broadcast production was conducted at the Women's Super League match between Chelsea Ladies and Manchester City Ladies at Kingsmeadow Stadium on Thursday 1st February 2018. Permission was negotiated via BT Sport for access to observe and record the production to allow a full analysis of the workflow and interactions at a later date without having to impact the live event itself. Pre-installed Go Pro cameras that captured the pre-broadcast preparation and live broadcast activity within the main gallery of Timeline's UHD2 match truck recorded Timeline TV, Moov TV and BT Sport production staff. These videos were composited into a synchronized quad view video along with the broadcast output to provide an invaluable replayable asset for the project. Specific emphasis had already been given to the live trial in replicating the current match GFX in an object-based workflow. So particular analysis of the interaction between the director and the graphics operators (Moov TV) was generated from this video in the form of a graphics timeline for the standard template of assets used with a football match.

2.2 Experience

The experience was defined to be a multi-screen experience involving a single primary shared screen (Main TV) coupled with a companion device (Tablet). The design principles applied to the Football at Home experience were:

- For the BT Sport directors broadcast mix of the game (along with commentary) to remain central to the experience.

- To allow the match experience to be enhanced with additional media objects to create a different ways to watch the match based on the viewers interest or allegiance.
- For the broadcast (TV) and digital (App) match experiences to feel like a single joined up experience.
- To blur the boundaries of user perception between traditional non-interactive TV graphics on TV and the interactive GUI of digital player (tablet/phone) which are still often disconnected in terms of technology and visual aesthetics.
- To create responsive graphics that adopt the appropriate scale, location and design based on different screen sizes and interactive features (e.g. safe zones for TV or a touch screen companion device).
- To retain a level of control over the quality of the match presentation by applying rules for TV and companion app layout and rendering of Match GFX based on content type, screen type and context of broadcast.

Two iterations of the experience were applied during the project. The first (version 1) was created and tested during the live end-to-end football trial described in this report. The second (version 2) was an iteration of the design with simplifications and additional features added to the clients for presentation of the experience as an "as live" demonstrator at IBC in September 2018 (see Section 4).

The version 1 experience designed for the live trial that would achieve two objectives:

- Deliver a full screen OBB TV presentation replica of the match graphics using ChyronHego's PRIME workflow solution
- Provide a GUI video overlay for the companion App that and provides access to and selection of live media objects in the trial. These include match data (team sheets and match stats), video on demand assets (replays) and live video streams (ISO cameras).

2.2.1 TV Match Graphics (GFX)

No unique design process was required to re-create the BT sport Match GFX other than to closely replicate the style, layout and animation of existing on screen TV graphics via the ChyronHego Prime authoring tool. Prioritization decisions were made on exact graphics to include/exclude based on their complexity and re-use to ensure maximum return on effort. Style guides were created by the project so that PRIME updates for each of the three trials included the correct team variables.

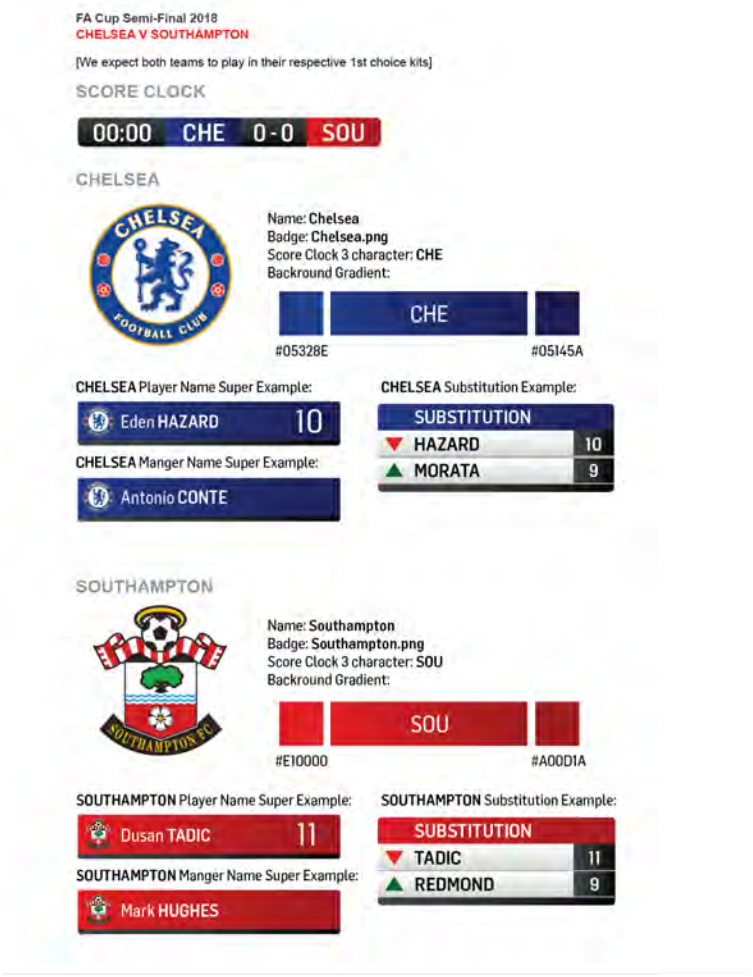


Figure 6. The graphics style sheet created for the FA Cup Semi-Final test

2.2.2 Graphical User Interface (GUI) Video Overlay

To ensure design principle of merging TV Match GFX and companion app GUI overlay into a single experience - the BT Sport design style was adopted and extended to ensure the companion app appeared as one part of a unified experience.

This also included constraining the GUI to the location of existing on screen graphics that appeared above the match score clock and channel BUG. To launch the menu the user could tap the existing on screen Match GFX (the omi present score clock) to access more media about the match. A series examples can be seen in below extract from the style guide created for the Score Clock Menu which includes access to the 4 tabs: Match Overview, Match Stats, Team Line ups and Replays. Figure 7 shows the different tabs within the Score Clock interactive GUI.

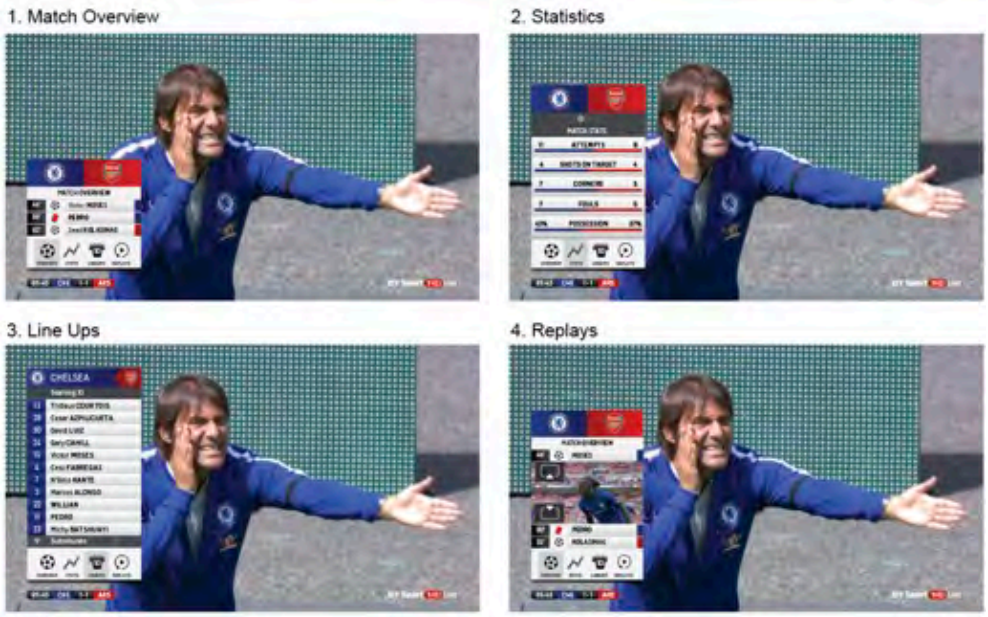


Figure 7. Different tabs within the Score Clock interactive GUI.

2.2.3 Video Thumbnail Menu

A common interaction design used across both live streams (ISO cameras) and on demand video (match replay clips) was the video thumbnail menu. Each menu bar for replays or cameras could be expanded to play a thumbnail video of the associated media (see Figure 5). This video thumbnail was overlaid with button icons providing options to move this content 'up to the TV' or 'down to your device'. Once this decision was made, based on the layout rules associated with the selected content the viewer may be presented with further layout options (if available) to play the content as full screen, dual screen (side by side) or PiP (Picture in Picture). Figure 8 shows a breakdown of the video thumbnail menu.

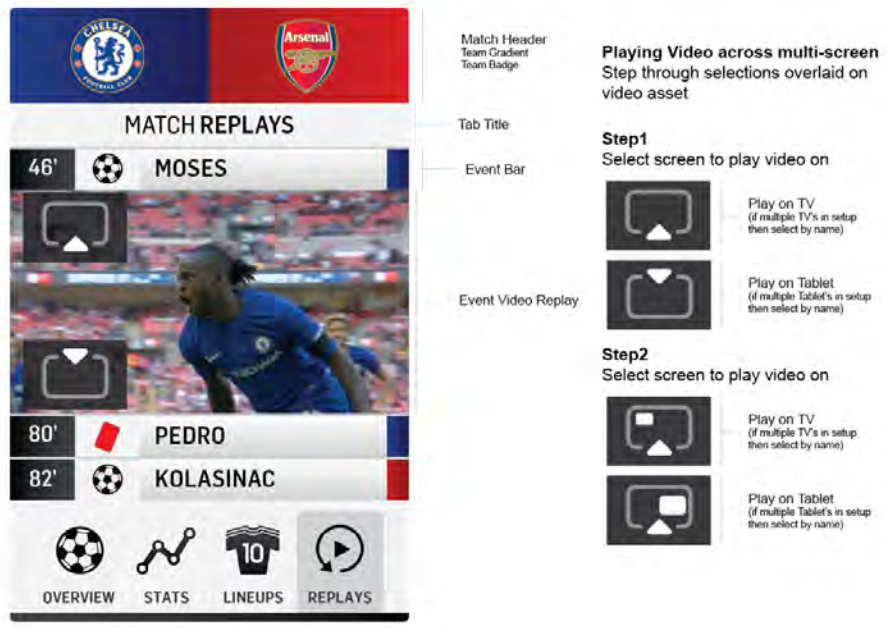


Figure 8. A breakdown of the video thumbnail menu

Although full design and documentation process was undertaken for the UX of the live trial, not all features were fully iterated before the final live trial at the FA Cup Final in May 2018. The live end to end trial was undertaken with the emphasis primarily as a technical test with only a limited number of home viewers were sufficient UX features existed to allow the technical features to be proven. With the live tests complete the UX of the Football at Home (along with the Fan Zone layout) was iterated to version 2 for presentation at the 2-IMMERSE stand in the IBC Future Zone. Significant learnings were taken from the version 1 experience to simplify and enlarge the GUI elements while retaining the core design principles.

2.3 Production Tool

Previous work of the research team resulted in a novel model and workflow for production tools that allow for object-based broadcasting [5, 7]. The tools were intended for covering MotoGP races, but we had the intuition that they could be adapted for football, and other sports as well. We thus arranged a number of conversations with professionals working on TV sports broadcast and carefully observed the recordings from the OB truck at the FA Women's Super League football game. Drawing on the focus groups and the observations, we concluded that our previous work was a good starting point, but required some modifications. First, all controls should be easy to manipulate and to target. Second, the person preparing the content for, for example, replay clips is not the same one as the person who decides when and if the content is inserted into the broadcast. Several people share the former task, whereas either the director or a vision mixer usually performs the latter. Finally, we learned that in the truck there are a lot of special-purpose hardware devices with big buttons and dials, providing quick access to specific functions. The next sections details the successive iterations and shows the final version of the production tools used during the event.

2.3.1 Iterations of the Live Triggering Tool

The system used at Wembley stadium on the day of the event consisted of a couple of screens, laptops with our software and two hardware encoders, which encoded the raw feeds and uploaded them to our infrastructure. The system was set up in an OB truck located in the broadcaster's area of the stadium. The truck received the main raw feed as edited by the director and team responsible for the actual TV broadcast. We were then able to edit the feed using our live-production platform by e.g. toggling in-program-promotions, the score clock or name-popups for players.

During the development of the triggering tool for FA Cup, we went through several phases and iterations to arrive at the two-application solution with hardware integration that we have now. The idea for the triggering tool first came about in summer last year (after the ethnographic study at MotoGP [7]), where we saw the opportunity that it might be interesting to insert snippets of timeline documents into a host document while this host document was being played out. After evaluating the technical feasibility of this idea on the server side as well as on the client, we were able to quickly implement a rough first prototype.

This first prototype (Figure 9) was able to read and retrieve specially annotated snippets of timeline code, so-called "events" from a running document and render them into a user interface. In this first prototype, the events were rendered as a list containing the name, a thumbnail and a button to insert the event into the running presentation. Some events can have one or more parameters. These parameters can be text (e.g. the text for a label to be shown on screen), numbers or predefined selections. In this case, the trigger button will only be enabled after the parameter field have been filled in.

Pressing the "show" button causes the interface to send the unique identifier associated with the selected event and optionally its parameters to the server which then prompts the timeline server to insert the event into the running broadcast. Consequently, the triggered event will be displayed in a separate list of "Live Events", from where it can be disabled again, i.e. removed from the broadcast.

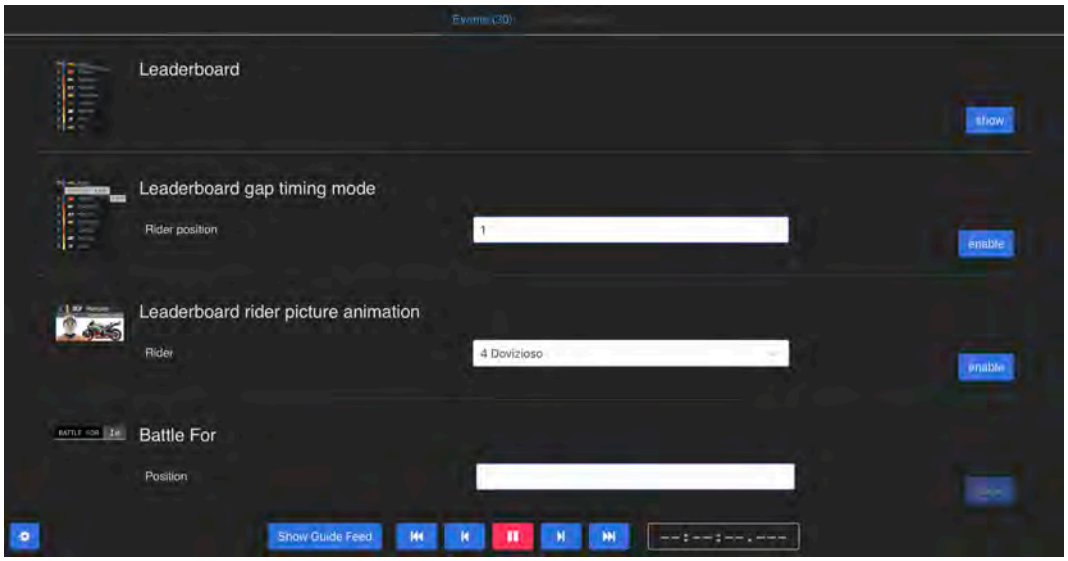


Figure 9. The first prototype of the live triggering tool

In late summer of 2017, two members of our team visited the MotoGP held at the Silverstone circuit in the UK. During the race, they were given access to the OB truck responsible for the live-broadcast of the race for the UK. This was used as an opportunity gain insight of the different roles and division of labour in an OB truck. Perhaps unsurprisingly, we learned that the work during a live broadcast is highly time-critical and each person in the truck had a very specific task and had to rely on the other people to complete their tasks in a timely manner. Otherwise the delay would propagate all the way and potentially negatively impact the live broadcast.

Moreover, this being such a time-critical environment, we realised that the current solution with the two tabs may not be ideal and also the events would benefit from being presented in a more compact way. So, the second iteration of the triggering tool did away with the tabs and presented the events inside boxes, so several of them could be presented in the same row. Also, instead of currently active events being displayed in a separate tab, they would simply be highlighted in green. Clicking the button in an active event would consequently disable it, remove it from the stream and remove the green highlight so it can be triggered again. Finally, we found that the parameter input field provided too much of a visual distraction. Instead of the parameter input fields being rendered in the event containers, in this new version, events with parameter have a button labelled “configure”. Clicking this button causes a modal window to appear, where the parameters can be filled in and the event can then be triggered with the click of a button.

After some experimentation with the new platform, we sat down with TV professionals who worked with sports broadcasts at BT Sport asking for their opinion. They were very positive about the usefulness of the solution and we were able to compare our solution to similar solutions which are currently being used during traditional live broadcasts. The main takeaway from these discussions was that producers are extremely familiar with the software they use and have to rely on the fact that all controls are easy to manipulate and easy to target, i.e. clickable surfaces must be big enough. This resulted in a few minor adaptations of the user interface and in the way the events can be arranged on the screen.

Later on, we were also able to obtain a recording of the work happening in an OB during a FA Women’s Super League football game. This allowed us to study the processes in the truck in greater detail. We quickly realised that the person preparing the content for things like name popups or replay clips is different from the person which has the final say on when and even if that content is inserted into the broadcast. The former task is shared by several people whereas the later task is usually performed by either the director or a vision mixer. This prompted us to add to add a second mode of operation to the triggering tool. The old mode, now dubbed “Direct Trigger” mode was supplemented

by a “Queueing” mode.

The new mode of operation allowed us to separate the preparation of events (i.e. filling in of parameters) and their actual insertion into the live broadcast into two, potentially even more independent parts of the workflow. To that end, when launching the triggering tool, the user selects the option “Queue events” when loading the document. Now, whenever an event is launched it is not directly inserted into the broadcast, it is merely added to a queue of configured events. Events in this queue then show up in a second application, called “Triggering Launcher”. It’s interface is very similar to the triggering tool, albeit simpler. Upon launch, the application prompts the user for a URL of an instance of the triggering tool, fetches a list of active broadcasts to which the user could attach the application to. The task of this triggering launcher is to render events from the queue created by the triggering tool and insert them into the running broadcast when triggered. The architecture of the platform naturally allows the queue for the triggering launcher to be fed by multiple triggering tools, provided they are all attached to the same input document. For instance, one could imagine one person being responsible to on-screen labels, while someone else being responsible for the creation of replay clips. These people could work on different machines, while all prepared events in the end arrive at the same instance of the triggering launcher controlled by the director.

Initially, the communication between the triggering tool and the launcher was facilitated by a HTTP long-polling method over a REST API, where the launcher would query the server for an updated version of the event queue every 2.5 seconds. This however, was found to be too much of a delay as it could happen that, in the worst case, if an event was queued, it could take up to 2.5 seconds until it showed up on the launcher interface. Reducing the time between polls proved to be counterproductive as it put more of a strain on the responsiveness of the user interface in general. After deliberations, we found that the long-polling method could rather easily be replaced by a WebSocket-based publish-subscribe solution. In this solution, the triggering launcher registers its interest about updates to the event queue for the selected document instance at a WebSocket server. The triggering tool, in turn, whenever the queue changes in any way, sends the most recent copy of the data structure to that server, which then makes sure the triggering launcher is informed about the update immediately. Therefore, changing the communication model from a pull-method to a push-method, with updates propagating almost instantly, while keeping the user interface as responsive as possible.

When in queueing mode, the triggering tool also slightly changes its appearance. In this mode, a bar on top shows events that are currently queued. Inactive (i.e. not yet triggered) ones are highlighted in a dark orange tone, whereas active ones are highlighted in green. The operator of the triggering tool can also remove events from the queue by clicking the close icon next to inactive queued events. This is useful for instance, if an event has been erroneously added to the queue or the director decides, that the event should not be inserted into the broadcast and wants to make way for new events. Active events cannot be dropped from the queue until they have been removed from the broadcast first. In this mode, both, the launcher and the triggering tool have support for persistent events. This type of event depends on a flag to be set for it in the source document. Events with this flag enabled are immediately added to the queue and stay queued even after activating and deactivating them. This is different from all other events, which are, after being inserted into the broadcast and subsequently deactivated, removed from the queue. This is useful for on-screen labels with player names, where the triggering tool operator queues an event with the desired name, the director activates and then removes it. This specific label might not be used again in the broadcast, so it can be dropped from the queue to make space for other events. Persistent events, though, are things like the score clock in a football game. The clock won’t appear until kick-off, is going to stay on screen until half-time, will be removed in the break and be brought on again for the second half. In this case it makes less sense to queue the same event (i.e. the activation of the score clock) over and over again.

Another detail we learned from the recording of the Women’s Super League broadcast was while there are a lot of computers being used in the OB truck, a lot of the work is performed on traditional single-purpose hardware devices with big buttons and dials. This informed our decision to make the triggering launcher a native desktop application instead of a web application, as is the case with the trigger tool. Specifically, a desktop application gives us the possibility to interact with hardware

devices, for instance over USB. One such hardware device that we integrated support for is called *StreamDeck*, which is sold as a device for online streamers. It is a little black box with 15 hardware buttons, where each button is backed by a 72x72 pixel LCD screen, plugged into the computer via USB. This enabled us to map the events rendered in the triggering launcher onto the buttons, allowing the user to conveniently launch and modify events quickly from this console instead of having to use the mouse and click the corresponding button on the computer screen, thus resulting in quicker and more precise triggering of events.

2.3.2 The Design of a New Live Triggering Tool

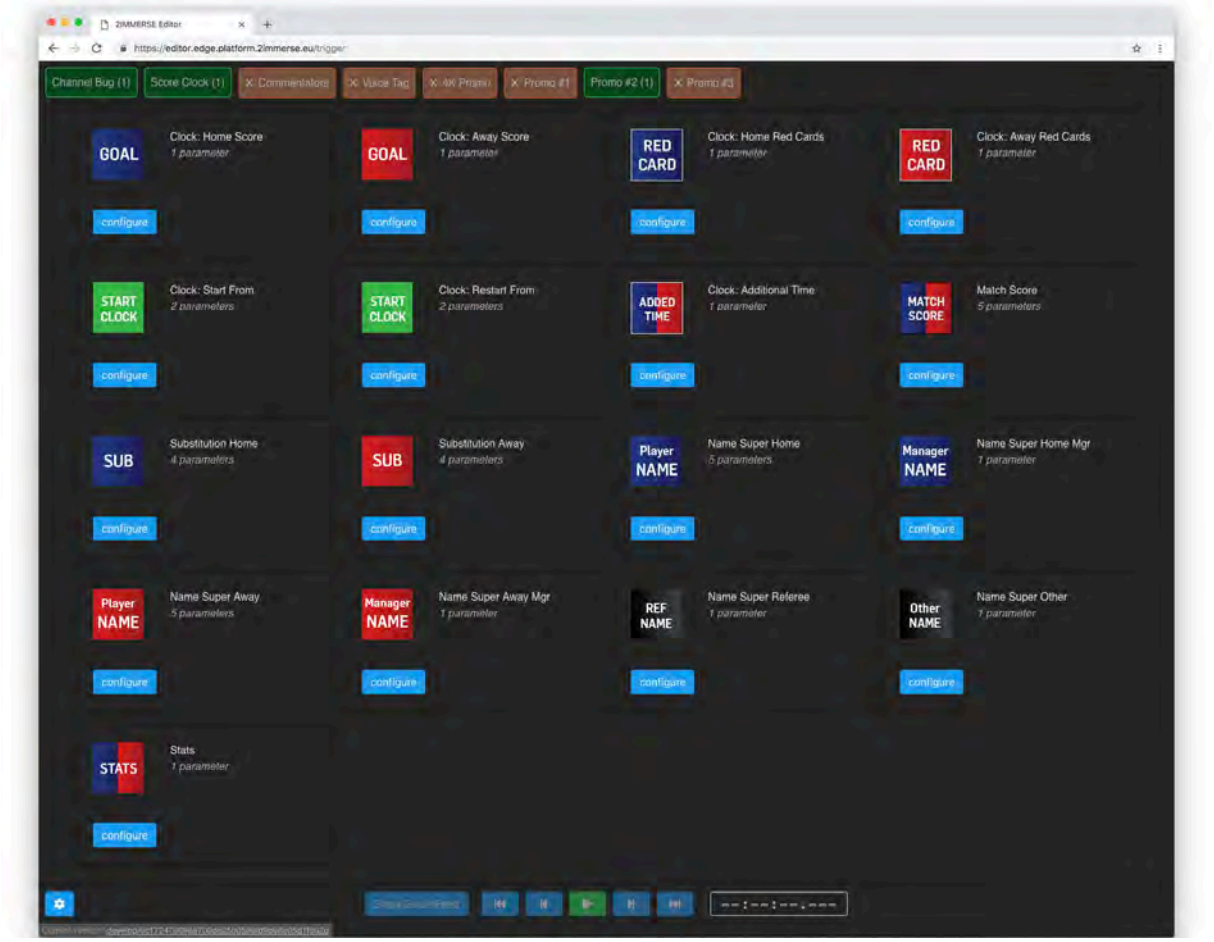


Figure 10: Triggering tool in operation in- side a web browser

Based on the new requirements gathered from the iterations, we designed a new version of our live triggering tool, diving it into two sub-tasks, each one targeted at a different professional. The first tool, called *Triggering Tool* allows to prepare media related to the events, such as replay clips or inserting on-screen labels and queueing them for the director to launch (Figure 10). The second one, called *Trigger Launcher*, intended for the director, can be used for launching the events when ready, i.e. inserting them into the broadcast (Figure 11, top). For the second one, we were able to integrate support for *StreamDeck*, a hardware device intended for video-game streamers. The device is equipped with 15 hardware buttons, where each button is backed by a 72x72 pixel LCD screen, plugged into the computer via USB (Figure 11, bottom). This enabled us to map the events rendered in the trigger launcher application onto the buttons, allowing the user to conveniently launch and modify events quickly from this console instead of having to use the mouse and click the corresponding button on the computer screen.

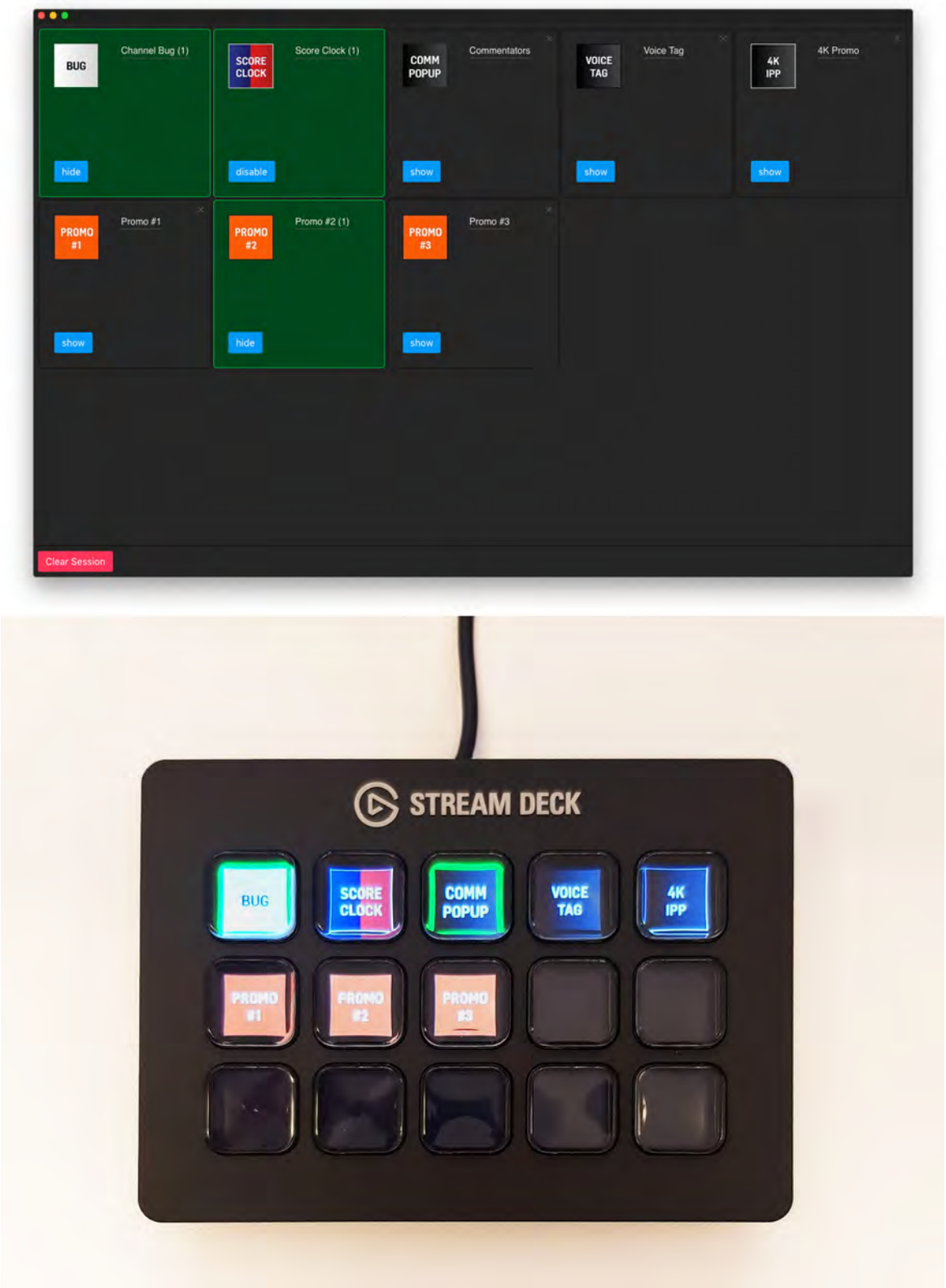


Figure 11: Trigger launcher (top) and hardware device *StreamDeck* (bottom) for operating it more conveniently

2.4 Graphics

Object-based broadcasting provides user-level personalization and it thus requires all broadcast graphics (non-video visualizations overlaid on top of the video) to be composited on the client device. This is a major shift from traditional broadcasts, where all graphics are overlaid and burnt into the transmission signal at the OB Truck. This requires new and more flexible ways to author graphics. Experience from previous trials, where we took on a quite developer-centric approach to coding such graphics in HTML and JavaScript, showed that the process was cumbersome and time-consuming. The design of these graphic elements and animations are valuable assets for a broadcaster and are thoroughly defined and specified down to pixel perfection.

For the FA Cup Final we wanted to try out a more designer-friendly approach utilizing an existing broadcast WYSIWYG graphics authoring tool. The tool we choose was ChyronHego Prime. Using the ChyronHego Prime scene description file format, the researchers created a specialized renderer for object-based broadcasting which can live execute Prime-authored graphics in the client devices. At the FA Cup Final, ChyronHego Prime (see Figure 12 and 13) was also used for creating the traditional broadcast graphics (4K HDR), so we were able to re-use assets created for the broadcast graphics in the object-based broadcasting workflow as well.

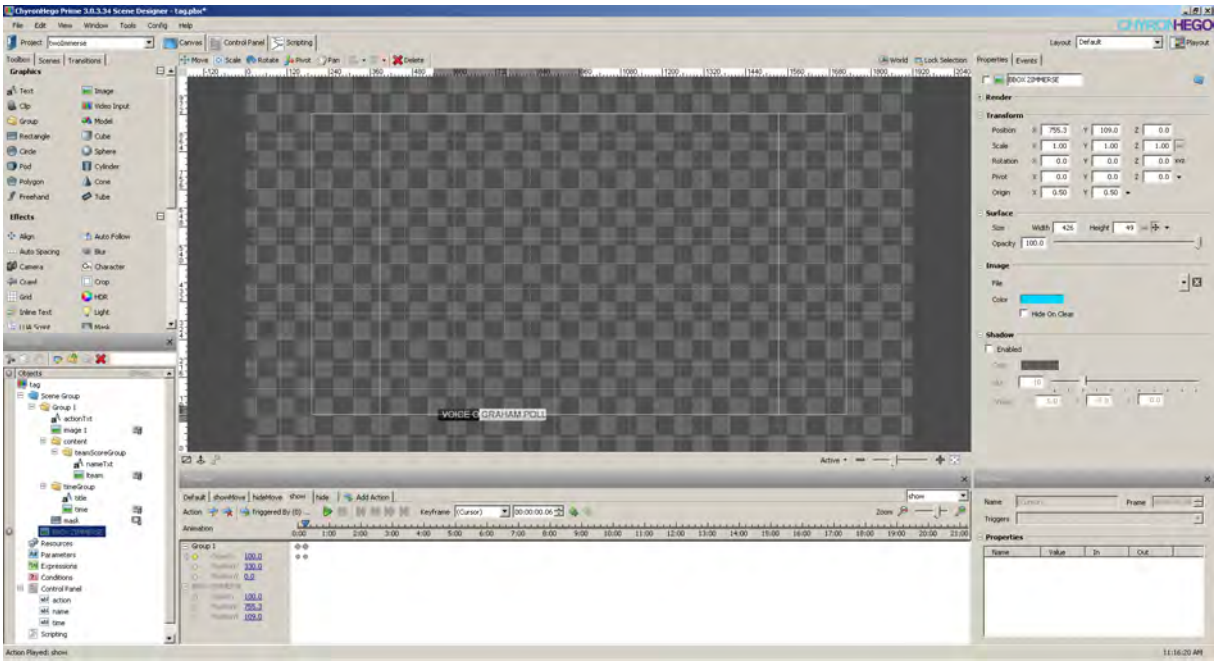


Figure 12. A screenshot of ChyronHego Prime

The created renderer parses the native xml-based storage format Prime uses and create an internal scene tree representation of the content. This means no “exporting” is necessary in the workflow. Parameter bindings, i.e. dynamic information in a graphics item, for example the name in a lower third name strap, are configured inside of the Prime designer. These are picked up by the renderer and fulfilled by information inside the timeline document.

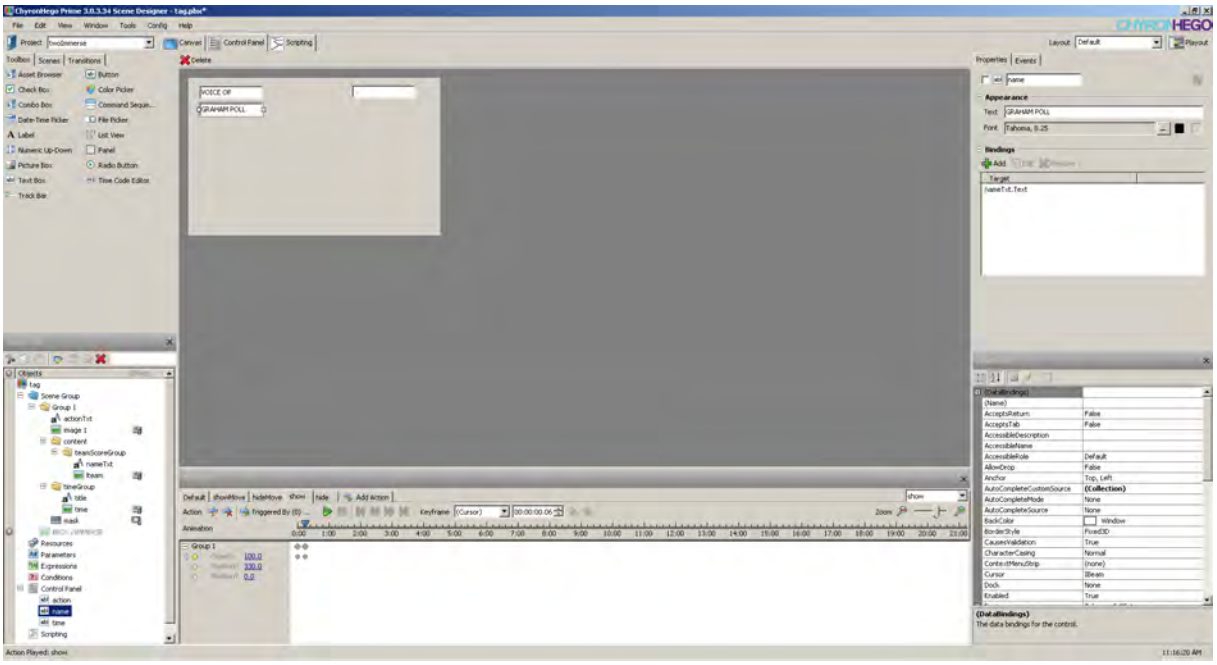


Figure 13. ChyronHego Prime, parameter building.

```
<tl:par>
   <tl:sleep tl:dur="30" />
   <tl:sleep tl:dur="0" />
   <tl:ref tim:class="PrimeDMAppComponent"
      tim:url="https://origin.platform.2immerse.eu/deployment/edge/dmapp-components/prime/prime.html"
      tic:scene="tag.pbx"
      tic:action="show"
      tic:name="Graham Poll"
      xml:id="tag-1"
      title="tag"
      tim:constraintId="region-tag" />
</tl:par>
```

Figure 14. Example of databinding inside a timeline xml. In this case, the name (Graham Poll) is dynamic.

Differently from MotoGP, where each graphic item, became one specific DMApp Component, now only one component exists, which is instantiated many times, referencing different (or same) Prime scene files, using timeline parameters to fulfill the dynamic information. The renderer uses WebGL as its primary choice to utilize GPU resources on the client for a smooth graphic experience. If this is not possible it will fall back to HTML canvas-based rendering. A nice side effect of using such a tool as design tool is that created graphics could be used on more than one platform. If a broadcaster already has Prime created resources these would be available as 2-IMMERSE graphics as well. But the real benefit is that a designer can do the graphics implementation without a developer.

3 Object-based Broadcasting during the FA Cup Final

After the preparation work described in the previous section, the research team was (almost) ready to bring a unique football experience during the FA Cup Final at Wembley Stadium to people's homes. The football experience was to be a unique, object-based broadcast, since multiple media objects could be assembled in a personalized manner and rendered on different screens (Figure 15).

Figure 15. Experience at home as viewed by an end user: television screen (top), tablet (middle) and user-customizable screen configurations for companion screen (bottom)

As explained in Section 2, live tests were carried out during two match events prior to the FA Cup Final. A delivery plan was developed in which the first event on 22nd April was used to gain familiarity with the OB facilities at Wembley Stadium and to test live content acquisition and distribution, plus live triggering of production graphics as far as possible while being aware that further development would be required to complete the client experience following this event. The second event, on 12th May, was used as a 'dress rehearsal' to test end-to-end system performance and

identify remaining issues to be addressed prior to the final event on 19th May. At this event, a full live end-to-end test was carried out, with the first version of the client experience delivered to a small number of project team members in their homes. The FA Cup Final event was used for two additional purposes:

- To capture all of the content and data which would be used to create the as-live Football at Home and Football Fanzone experiences which were later demonstrated at IBC 2018.
- To test the creation and capture of synchronized camera and player tracking data using the ChyronHego TRACAB and Virtual Placement systems, so that this data could be used at a later stage to demonstrate object-based virtual graphics.

Figure 16 below shows an overview of the key system components which were used during the full live end-to-end test during the FA Cup Final on 19th May 2018. The architecture for the preceding two live events was essentially the same, although some components were not available or not used at these events. The live tests made extensive use of existing resources, integrating with external production components as far as possible. The blue boxes and symbols in Figure 16 represent existing components, while the green boxes and symbols highlight additional components developed or acquired for 2-IMMERSE.

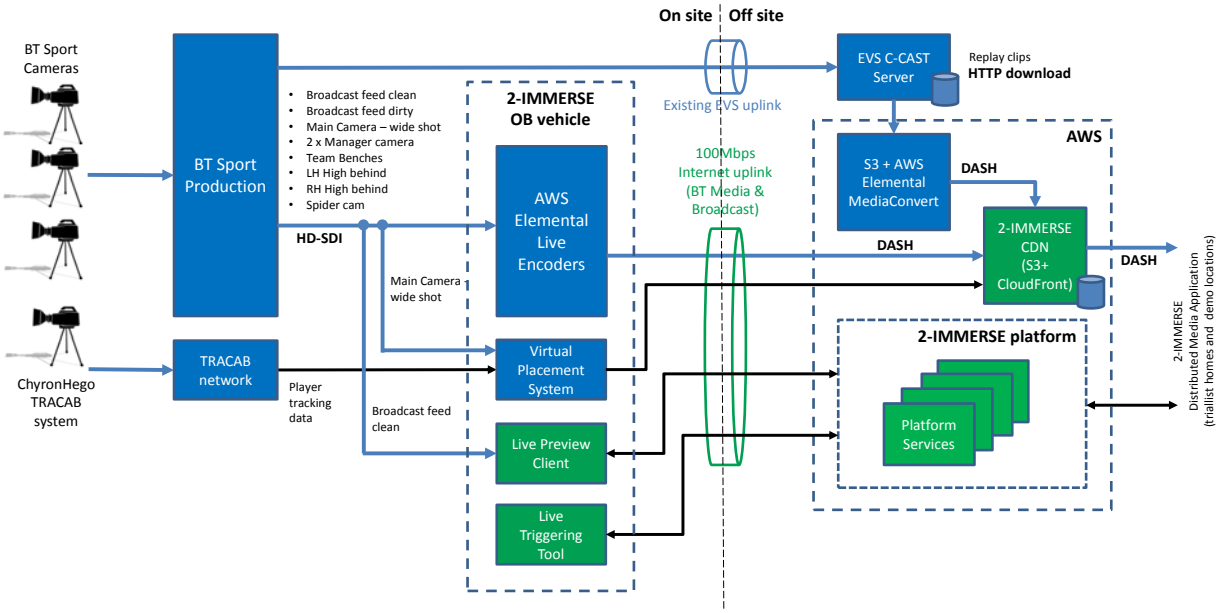


Figure 16. System architecture for 2-IMMERSE live end-to-end tests.

3.1 On-site components

The deployment at Wembley Stadium was centered around our own OB vehicle, a Mercedes Sprinter van fitted with two small work areas and basic services such as power, cable routing, air conditioning and lighting. This vehicle was essential as a space to safely host and operate the additional components required for object-based broadcasting. The vehicle was provided by BT Sport supplier Telegenic, who also provided personnel to support the 2-IMMERSE team during the tests. Given that none of the 2-IMMERSE team had experience working in an Outside Broadcast environment, the Telegenic team were essential in helping gain access to the necessary infrastructure and live feeds which were needed. The 2-IMMERSE team were fortunate that the same vehicle was made available for all three tests, and they received technical assistance from Telegenic's Head of R&D for the first test and the FA Cup Final.

In addition to the architecture described below, the Telegenic team provided a listen-only feed of the Match Director's talkback channel within the 2-IMMERSE vehicle. This enabled the 2-IMMERSE team to hear the majority of vision and graphics cues throughout each match and thus test the object-based production tools in a representative way.

3.1.1 Live camera feeds

A key feature of the object-based multi-screen football prototype is the ability for the viewer to select additional live camera streams to supplement the feed provided by the Match Director. For each live test, the project team requested access to a range of live camera feeds, most of which could be delivered to the client applications. These differed slightly between live tests because different camera plans were used for each match, but the full set used at the FA Cup Final were as follows:

- **Broadcast feed clean**: The Match Director's output with no overlaid graphics. This was the primary feed and default selected on both TV and devices.
- **Broadcast feed dirty:** The Match Director's output with overlaid graphics, as sent to broadcast viewers. This was displayed within the 2-IMMERSE vehicle as a reference stream and not delivered to client applications.
- **Main Camera – wide shot**: A fixed camera wide shot from the side of the pitch. This was also used as a reference image to calibrate the virtual placement system.
- **Manager cameras:** Two manned cameras which captured wide or mid shots of each team manager during the match. These were provided specifically for 2-IMMERSE.
- **Team Benches:** A wide shot showing the team benches.
- **LH and RH High behind:** Two cameras set behind and above the goal at each end of the pitch, intended to capture a fan's point of view.
- **Spider cam:** The robotic 'spider camera' which captures match details from above the pitch.

Each camera feed was provided in HD-SDI format in a separate coaxial cable routed from the BT Sport production truck to the 2-IMMERSE vehicle.

3.1.2 Live encoding

Two live streaming encoders were loaned for the duration of the tests by BT supplier AWS Elemental, who also provided technical assistance with configuring them and resolving issues. Each encoder was capable of live encoding a multi-layer DASH representation of 8 HD-SDI input streams. Once encoded, the DASH segments were uploaded to the CDN Origin Server, from where they could be consumed by the client applications. Given that the FA Cup Final match was simultaneously broadcast free-to-air in the UK, it was agreed that stream encryption need not be used, but instead access control was applied to the Origin Server so that client apps were required to authenticate before they could download the stream.

In order for these live camera streams to be delivered to the 2-IMMERSE Football client apps, they needed to be encoded into the MPEG-DASH adaptive bitrate streaming format which is used by the video player component within all 2-IMMERSE client applications. Although remote production is becoming more widely used within the industry for smaller live events, the practice for high-profile Wembley matches such as the ones used for the live tests is for production on-site, so there was no existing provision for the encoding and uplinking of additional streams from the cameras described above. A number of options were considered, including transmitting each stream in a near-lossless mezzanine format to a live streaming encoder in the cloud, and using a local live streaming encoder then uploading a multi-layer representation to the cloud. While the former option might be preferable for an operational solution, the latter, simpler option was chosen for the 2-IMMERSE live tests.

Two live streaming encoders were loaned for the duration of the tests by BT supplier AWS Elemental, who also provided technical assistance with configuring them and resolving issues. Each encoder was capable of live encoding a multi-layer DASH representation of 8 HD-SDI input streams. Once encoded, the DASH segments were uploaded to the 2-IMMERSE CDN Origin Server (as shown in Figure X), from where they could be consumed by the client apps. To avoid complexity and save uplink bandwidth, error protection was not used improve the resilience of the delivery of the MPEG-DASH representations to the 2-IMMERSE CDN. The MPEG-DASH segments were accumulated on the 2-IMMERSE CDN, which meant that only a small modification was required to the manifest to enable them to be played back on-demand after the match had finished.

As the end-to-end tests did not need to accommodate clients connected to a wide range of access networks, the following reduced set of video representations was proposed for the DASH MPD. These are based on the 'Premium' profile already used by BT Sport.

Layer	Resolution	Bitrate
2	1920 x 1080	6500kbps
1	1280 x 720	5000kbps
0	640 x 360	800kbps

In addition, single-layer audio representations were required to carry stereo audio tracks which contained the ambient audio from the stadium and the BT Sport commentary.

Content security was an important consideration during the design of the live tests, however the technical options available were limited by the cost of licences and support provided by the live encoders and the video player component within the 2-IMMERSE client applications. Given that the FA Cup Final match was simultaneously broadcast free-to-air in the UK, it was agreed that stream encryption need not be used, but instead access control was applied to the Origin Server so that client apps were required to authenticate before they could download the stream. This sufficiently mitigated the risk of third party access from outside the UK.

3.1.3 Internet uplink

The use of additional live encoders also necessitated the provision of Internet uplink capacity dedicated to the 2-IMMERSE Outside Broadcast vehicle. This proved to be the most challenging dependency across all three live tests, with different solutions tried at each, and only the solution used at the FA Cup Final providing sufficient capacity for the duration of the event. In order to upload the 3-layer MPEG-DASH representation shown above for 8 distinct live streams, while providing headroom for audio streams and signaling, at least 100Mbps upstream was required.

During the FA Cup Semi-Final on 22nd April, the BT Sport team provided a BT uplink, which was shared with other production and testing functions. While this showed good performance before the match, it became frequently contended during the match with the result that only one or two streams could be concurrently uploaded.

During the National League Play-off Final on 12th May, an uplink using Wembley Stadium infrastructure proved unable to provide consistent connectivity or bandwidth. For part of the match, this was exchanged for a dedicated BT uplink, which became available and the required level of reliable performance was achieved. This solution was subsequently provided for the FA Cup Final test.

Performance monitoring before the start of the FA Cup Final match suggested that uploading the representations for all 8 distinct live streams risked data loss from any of the streams by operating very

close to the maximum bandwidth available. Therefore, only 6 live streams were encoded and uploaded during the match, and the Team Bench camera and Spidercam were omitted.

3.1.4 Triggering interface

One half of the OB vehicle was dedicated to live triggering of object-based production graphics using the production tools described above. The tools ran on a laptop PC with the addition of an Elgato Streamdeck programmable keypad. The production tools communicate with our platform services, which were hosted off-site within an Amazon Web Services environment. The production tools were modified as well to enable the preview client to display the live feed from the capture device within the primary video player component, rather than opening the delayed MPEG-DASH stream from the CDN Origin Server.

It was also essential to provide a live preview of the graphics triggered by the production tools. This was achieved using a 2-IMMERSE TV Emulator client (based on an Intel NUC small form-factor PC) connected to a preview monitor adjacent to the tools. Unlike an off-site client device receiving MPEG-DASH streams over the Internet, the on-site preview needed to be synchronized with the dirty broadcast feed (the Match Director's broadcast output), which was used as a reference for the tests. To achieve this, an HD-SDI splitter was used to feed a copy of the clean broadcast feed into the TV Emulator client, using an HD-SDI to HDMI converter followed by an HDMI capture device. The production tools were modified to enable the preview client to display the live feed from the capture device within the primary video player component, rather than opening the delayed MPEG-DASH stream from the 2-IMMERSE CDN Origin Server.

3.1.5 Tracking

A headless camera tracking system (ChyronHego Virtual Placement) was set up independently of the live production tools in one half of the vehicle during the FA Cup Final event. Its purpose was to collect the main camera pose parameters during the game. These parameters are crucial for creating augmented graphics (graphics that blends into video as it was part of the three-dimensional scene). Traditionally, while burnt into the broadcast feed, these systems are used for adding billboards, rendering team logos on the pitch, visualize sport information as distance to goal on free-kicks, show offside lines and more. 2-IMMERSE researchers are using the captured data as research material to explore augmented graphics rendered in the client. At the same venue we also captured player tracking data from the ChyronHego TRACAB player tracking system, which determine the location of all the players in real-time. Having synchronized data sets with video, camera tracking and player tracking is valuable for future research in the object-based broadcasting domain.

3.2 Off-site components

3.2.1 The 2-IMMERSE platform and CDN

The 2-IMMERSE platform [5,6] was the most significant set of off-site components, playing a vital role in the delivery of the end-to-end live tests. Figure 17 identifies the main platform services which were used during the tests. As with all 2-IMMERSE Distributed Media Applications, the Layout and Timeline services were responsible for orchestrating the viewer experience on the TV and companion devices. In addition, for these tests it was also necessary to orchestrate the Live Preview Client. Another crucial extension to the platform was the ability for timeline updates which were created by the Live Triggering Tool to be automatically inserted by the Editor service within the active timelines of every client context which was watching the match, while accounting for the fact that off-site viewers' timelines would be delayed by up to a minute due to large buffers resulting from the MPEG-DASH live streaming configuration.

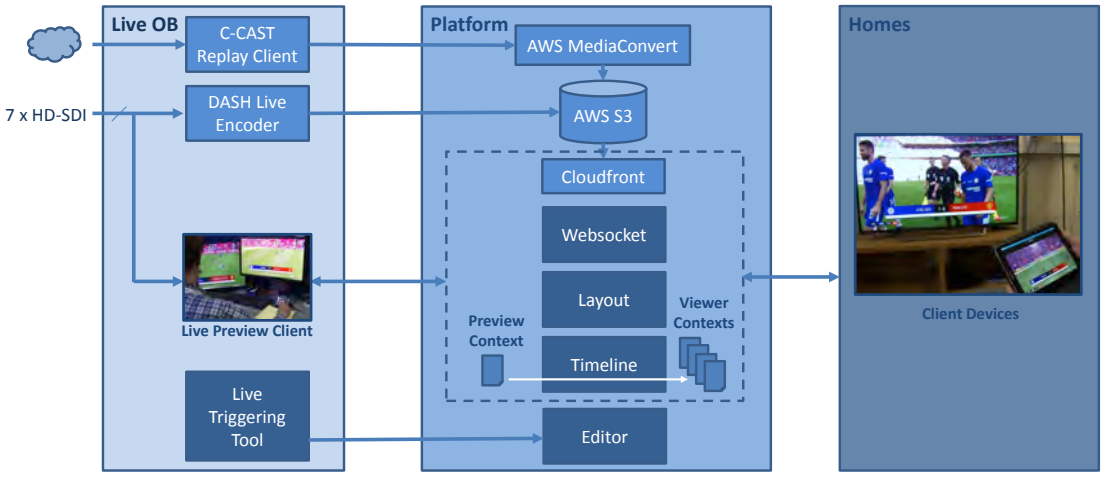


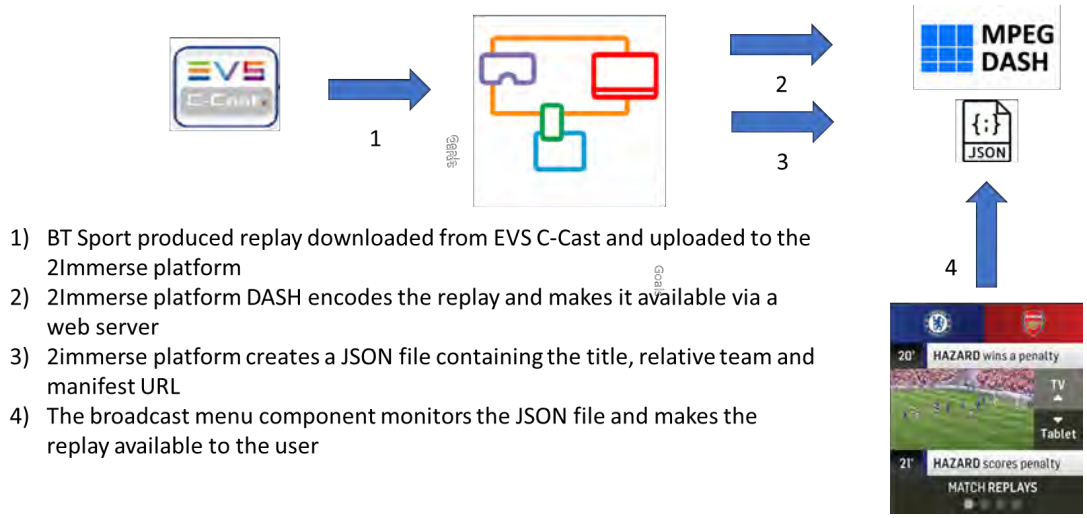
Figure 17. 2-IMMERSE Platform services used during the end-to-end live tests

3.2.2 Replay encoding and delivery

During some live events, the on-site BT Sport production team creates replays that are automatically uploaded to the EVS C-Cast platform for on-demand viewing and distribution to existing mobile applications. In order to provide interactive access to replays on demand within the 2-IMMERSE Football client applications, it was necessary to create an additional off-site workflow in which the required replays were extracted from C-Cast, converted to the MPEG-DASH adaptive bitrate streaming format, and made available on the 2-IMMERSE CDN Origin Server.

The BT Sport production team provided access to the C-Cast platform so that a member of the project team could manually select replay clips as required. For every significant match event, several different clips may be prepared – for example, showing different camera angles. For live end-to-end testing, it was decided to choose only one of these clips as a proof of concept, but it should be noted that there is considerable scope to automate the creation of one or more highlights packages.

Figure 18 shows the complete workflow developed for off-site replay capture, encoding and delivery. The project team configured an instance of cloud-based AWS Elemental MediaConvert to automatically encode replay files into a suitable MPEG-DASH format when uploaded to a specific Amazon S3 location. The encoded output is then automatically transferred to the 2-IMMERSE Origin Server, while at the same time the necessary metadata describing the reply is created so that the appropriate menus within the client applications can be updated to provide access to the replay.



1) BT Sport produced replay downloaded from EVS C-Cast and uploaded to the 2Immerse platform
2) 2Immerse platform DASH encodes the replay and makes it available via a web server
3) 2immerse platform creates a JSON file containing the title, relative team and manifest URL
4) The broadcast menu component monitors the JSON file and makes the replay available to the user

Figure 18: Replay capture, encoding and delivery workflow

This workflow could only be tested during FA Cup matches, when the EVS C-Cast platform was in use by BT Sport. During the FA Cup Final event, a technical problem with the BT Sport Outside Broadcast facilities meant that only a few replay clips were made available in C-Cast while the match was taking place. While this enabled the workflow-concept described above to be successfully tested, it was only after the match that all the replay content could be gathered and made available in the as-live version of the Football application.

4 Impact

The deployment of our infrastructure at an event such as the FA Final Cup demonstrates that we have successfully bridged the gap between lab research and key players in the production chain (e.g. BT Sports, MoovTV), motivating them to think of developing use cases or tools taking advantage of OBB. As noted by Bentley et.al. [3], the ethnographic-style field study can take new concepts to real users in early stages of development, quickly illuminating potential bottlenecks and challenges. The following sections illustrate the lessons learned from the process in terms of challenges and impact for the industry. We end this section describing some follow-up studies motivated by the success of the project.

4.1 New challenges for the industry

In our trial, the first challenge was to smooth the graphics creation workflow in this time-critical environment. To do so, we used an existing authoring tool (ChyronHego Prime) with a graphical interface but an XML-based storage format, enabling a designer to create graphics without needing a developer. However, the application was not specifically designed for OBB processes. New production tools to visually create OBB assets are needed.

The second challenge addressed is the usability of the live OBB production tool. A new version of this tool was separated into two parts. An assistant of the director uses one part to prepare and queue the media assets, the other part is for the director to launch the media assets in queues. The new version is expected to reduce the workload for the director and result in a smoother workflow. The third challenge we addressed was the live delivery of the objects triggered in the OB truck to the homes of all viewers in a timely manner. New preproduction tools for creating object-based broadcasting experiences are needed.

4.2 Impact on the industry

Based on the video assets collected, we developed a more complete and polished as-live multiscreen FA Cup demonstration, showing how production tools can be used to edit and broadcast graphics following an OBB approach. Together with the production tools, it exhibited how viewers can personalize their experiences through companion screens in home contexts. The demonstration was successfully presented at the Future Zone of IBC (Figure 19). It received a wide audience range including key stakeholders from the broadcast industry, academics, and production teams; all who believed "OBB is the future".

Apart from the Football at home, the Fan Zone experience presented at IBC 2018 included (Figures 20 and 21):

- A re-use of Football experience and layout templates across a range of clustered and isolated screens in the environment;
- The definition of 4 different content layouts, A classic mode (full screen replication on all screens) and 3 Multi-screen modes for neutral, home or away bias of the viewing supporters in the environment;
- The creation of a fan zone controller interface that allowed switching between the 4 defined content layouts;
- The re-use of the ‘at Home’ companion for mobile devices to sync with the Fan Zone experience to interact and view match content on personal screens.

Figure 19: Presenting the project at IBC 2018 in Amsterdam

Figure 20: Redesigned Football Experience for IBC 2018.

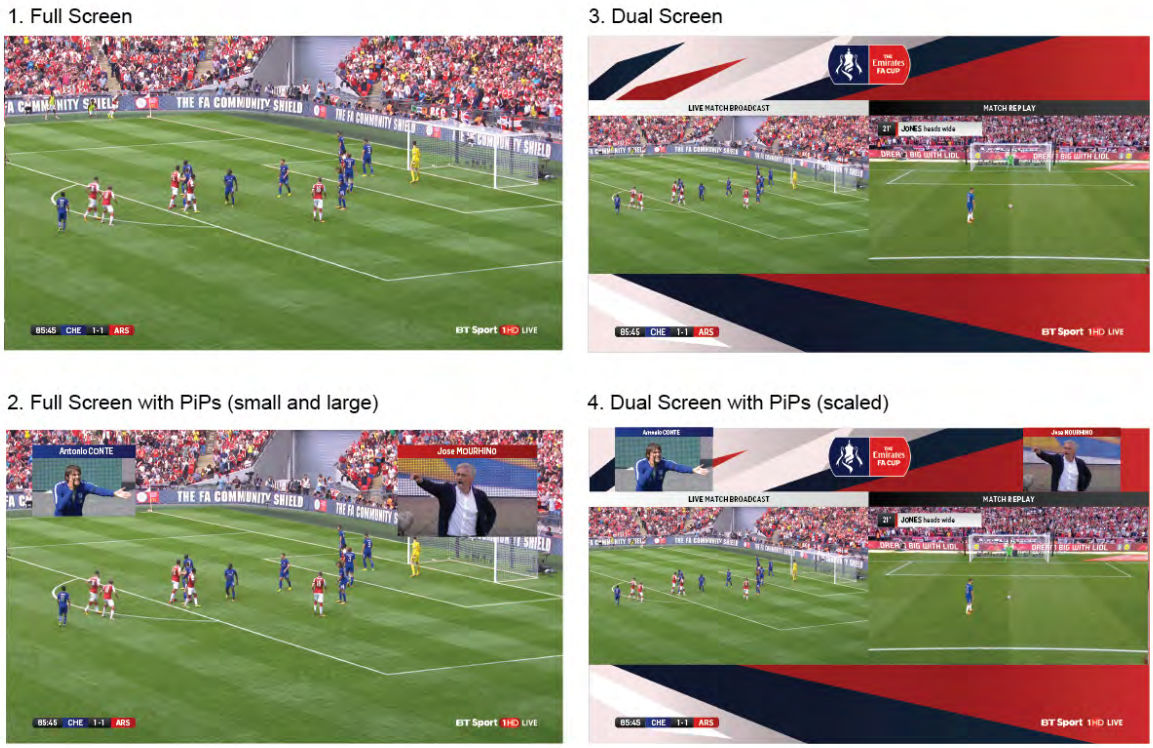


Figure 21: Different Layout Templates for the Football Experience.

4.3 Follow-Up Studies

To help integrate the OBB approach into the existing production workflow, the next step would be to develop a pre-production tool with a graphical interface, to allow people without programming skills to author multiscreen TV content. The preproduction tool aims at reducing the workload of the live broadcasting by creating a hierarchical overview of the content and arranging media objects on a storyline ahead of time [7]. The prototype of the pre-production tool developed during the project was tested by a group of producers and directors in the end of November 2018 in Manchester (details can be found in the deliverable D3.4).

Following 2-IMMERSE's presence at IBC, and in particular following the very positive assessment of the presentations by the COO of BT Sport (Jamie Hindhaugh), 2-IMMERSE were requested to provide a "mini IBC" to BT Sport personnel. Jamie invited his direct reports to brings teams to attend the session, intimating that the work "enabled personalisation and viewer control". On November 14th 2018 we presented the Football at Home, Football Fan Zone, and MotoGP demonstrations to BT Sport personnel. We completed eight sessions, each 30 minutes long, to groups of between 8 and 15 people at a time with varied skill sets: outside broadcast production (including match directors), broadcast communications, schedulers, media management, on-air navigation, creative designers, and application development and service. We used the sessions to probe the responses of media professionals to the challenges and opportunities associated with approach 2-IMMESRE was adopting. We did this through a questionnaire, which focused on the value and challenges associated with the different features represented in the demonstrations. We received 72 questionnaire forms from our visitors. Not all questions were completed; we received between 65 and 27 answers per question. The questions most likely to be answered related to the fan experience. We offered a don't know option (which was not counted) and some participants were unale to finish the questionnaier in the time available. In general, the responses suggested that all features would create increased engagement, though integarted communications and virtual AR graphics reported distinctly lower scores (means of 5.89 and 6.39 respectively) with respect to fan engagement than the other features. The features that

were assessed as adding greatest complexity to the production workflow included Virtual AR graphics and an adjustable audio mix.

5 Conclusion

The live trial at Wembley Stadium for the 2018 FA Cup Final was a milestone for the project. It undoubtedly helped us make the case for the Object Based Broadcasting approach that underpins the work done in 2-IMMERSE.

Through observing two live football matches, we were able to test the content acquisition and distribution process and to refine the design of the tools required to trigger all the match graphics in real time, during a live match. It proved important for two further reasons: firstly it gave the work of the project credibility, contacts and know-how that are required to have sensible conversations with the productions teams about the workflow required to enable object based media production; secondly it enabled us to collect relevant content in order to build, after the live event, a more polished reimagining of what the FA Cup broadcast could look like when an object based media approach was employed during production.

With respect to the first point we developed useful working relationships with a number of key people including:

- BT Sport Producer, upon whom we could rely to help iron out day to day issues needed to ensure the trials could run, Passes accreditation, bandwidth availability out of the stadium, a parking slot for our truck, the relevant camera feeds from the main truck etc.
- TIMELINE OBB truck provider – who provided the OB truck with relevant connectivity ports to allow us "plug in" to the infrastructure at the stadium and to accept the camera feeds from the cameras we required
- Chief technical Officer for BTSport, who took an active interest in the trial its output, look'n'feel, live operation etc. and reports to the COO of BT Sport
- Graphics operators for MoovTV who allowed us to watch the real time working practice of graphics operators during live events; that insight enabled us to develop a workflow based on the prototype tools developed with the project.
- MoovTV developers for their Report Builder tool used for live graphics, who were interested to understand more about the object based media approach we had adopted and to understand the implications that this approach might have for product development.
- Match Directors, who currently orchestrate the presentation of live matches. Working with match directors enables us to 'get inside their head' and helped us to incorporate their thinking into the way we subsequently reimagined the Football experience for a multi-screen experience.

The live trial was an essential stage on our journey to impact; success in the live trial helped us to retain the right to keep conducting experiments and to enable us to start conversations with key players in the overall live production chain. Being able to start these conversations has enabled us to plant seeds, like we have with MoovTV, with Match directors and with BT Sport influencers about the implications that the object based media approach may have for their link in the production chain.

A second important achievement, through the live trial was to collect all the video assets from the FA Cup broadcast, including five isolated camera feeds (home view, away view, Morinho Cam, Conte cam, broadcast feed, replays). With these assets in place designers and development teams in 2-IMMERSE could work to develop a polished multi-screen reimagining of the FA Cup Final showing how personalized multi-screen experiences can be developed for Fan Zone and at home experiences in ways that continue to take viewers 'closer to the heart of sport'. The demonstrations were presented at IBC the world's most influential media technology exhibition, through which 2-IMMERSE addressed a highly relevant audience of analysts, broadcasters and production companies. One of the key features

of the show, often of more interest than the new product technology pitches from the vast number of suppliers is the Future Zone where broadcasters and technologists are invited to review pre commercial innovations and to consider the implications on their industry. 2-IMMERSE took a stand in the Future Zone and there launched the open source software that supports all the object-based experiences the project has developed. To illustrate the capabilities of the platform we also demonstrated the Football Fan Zone prototype, The Theatre at Home prototype, the Football at Home prototype and the live triggering tool. All but the MotoGP demo depended absolutely upon the work done at Wembley. Perversely IBC, in Amsterdam, was also the first chance for some TV production teams related to BT Sport to see object based broadcasting. Critically the COO of BT Sport visited the stand seeing the football demos for the first time. Support from this key stakeholder is critical and we were delighted that he was supportive of the latest developments commenting: “This is the best thing I’ve seen at IBC; you just know that has been designed with the fans in mind”. More broadly we noted that visitors to the stand were particularly encouraged to see that the core parts of the 2-IMMERSE software platform were being made available through open source software licenses. We also noticed that every time we showed the Fan Zone demo, they smiled and we lost count of the number of times we were told “I like that” and “this is the future”.

References

[1] Mike Armstrong, Matthew Brooks, Anthony Churnside, Michael Evans, Frank Melchior, and Matthew Shotton. 2014. Object-based broadcasting-curation, responsiveness and user experience. (2014).

[2] Frank R Bentley. 2017. Understanding Secondary Content Practices for Television Viewing. In Proc. TVX '17. 123–128. [3] Frank R Bentley and Michael Groble. 2009. TuVista: meeting the multimedia needs of mobile sports fans. In Proceedings of the 17th ACM international conference on Multimedia. ACM, 471–480.

[4] John Dowell, Sylvain Malacria, Hana Kim, and Edward Anstead. 2015. Companion apps for information-rich television programmes: representation and interaction. Personal and Ubiquitous Computing 19, 7 (2015), 1215–1228.

[5] J Jansen, D Bulterman, and P Cesar. 2018. Workflow Support for Live Object Based Broadcasting. DocEng.

[6] Ian Kegel, James Walker, Mark Lomas, Jack Jansen, and John Wyver. 2017. 2-IMMERSE: A Platform for Orchestrated Multi-Screen Entertainment. In Proc. Adj. TVX '17. ACM, 71–72.

[7]JieLi,ThomasRöggla,MaxineGlancy,JackJansen,andPabloCesar.2018.ANewProductionPlatformfor Authoring Object-based Multiscreen TV Viewing Experiences. In Proc. TVX '18. ACM, 115–126. https://doi.org/10.1145/3210825.3210834

[8] Jie Li, Zhiyuan Zheng, Britta Meixner, Thomas Röggla, Maxine Glancy, and Pablo Cesar. 2018. Designing an Object-based Preproduction Tool for Multiscreen TV Viewing. In Proc. CHI EA '18. ACM. https://doi.org/10.1145/3170427.3188658

[9] Sidneyeve Matrix. 2014. The Netflix effect: Teens, binge watching, and on-demand digital media trends. Jeunesse: Young People, Texts, Cultures 6, 1 (2014), 119–138.

[10] Jim Owens. 2015. Television sports production. Focal press.