

# Integrating Augmented Reality to Enhance Expression, Interaction & Collaboration in Live Performances: a Ballet Dance Case Study

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## ABSTRACT

The democratization of high-end, affordable and off-the-shelf sensors and displays triggered an explosion in the exploration of interaction and projection in arts. Although mostly witnessed in interactive artistic installations (e.g. museums and exhibitions), performing arts also explore such technologies, using interaction and augmented reality as part of the performance. Such works often emerge from collaborations between artists and scientists. Despite being antonymic in appearance, we advocate that both fields can greatly benefit from this type of collaboration.

Since 2006 the authors of this paper (from a research laboratory and a national ballet company) have collaborated on augmenting a ballet performance using a dancer's movements for interaction. We focus on large productions using high-end motion capture and projection systems to allow dancers to interact with virtual elements on an augmented stage in front of several hundred people. To achieve this, we introduce an 'augmented reality engineer', whose role is to design the augmented reality systems and interactions according to a show's aesthetic and choreographic message, and to control them during the performance alongside light and sound technicians.

Our last production: *Debussy3.0* is an augmented ballet based on *La Mer* by Claude Debussy, featuring body interactions by one of the dancers and backstage interactions by the augmented reality engineer. For the first time, we explored 3D stereoscopy as a display technique for augmented reality and interaction in real-time on stage. The show was presented at Biarritz Casino in December 2013 in front of around 700 people.

In this paper, we present the *Debussy3.0* augmented ballet both as a result of the use of augmented reality in performing arts and as a guiding thread to provide feedback on arts-science collaboration. First, we will describe how the ballet was constructed aesthetically, technically and in its choreography. We will discuss and provide feedback on the use of motion capture and stereoscopy techniques in a live show and will then broaden the scope of discussion, providing feedback on art-science collaboration, the traps and benefits for both parties, and the positive repercussions it can bring to a laboratory when working on industrial projects.

**Keywords:** augmented performance, movement interaction, dance, augmented reality

**Index Terms:** J.5.2 [Computer Applications]: Arts and Humanities – Arts, fine and performing; H.5.2 [Information Systems]: Information interfaces and presentation—User Interface

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## 1 INTRODUCTION

Performing arts have long explored different technologies on stage. Sound and lighting require dedicated technicians both prior to and during a show. Very quickly, artists began experimenting with video on stage, then projection and interaction. In 2006 ESTIA and Malandain Ballet Biarritz (MBB) began an ongoing collaboration to explore both movement interaction and augmented reality in performing arts. This led us to produce several augmented shows and to introduce the role of the "augmented reality engineer" who works alongside light and sound technicians to set up the hardware and software elements required to augment a live performance. In this paper, we present our latest project and performance: *Debussy3.0*, which is an augmented, interactive ballet, bringing on stage movement interaction and stereoscopic 3D projection (cf. figure 1).



Figure 1. Scene from the augmented ballet *Debussy3.0*. © J. Morin

### 1.1 Related works: augmented and interactive shows

We seek to explore the potential of using augmented reality (AR) in the context of a ballet dance show to better convey the choreographer's message and suggest innovative artistic situations. Several augmented shows have been conducted over the last twenty years. The evolution of technologies and systems in the field of AR have allowed performance artists to use them as tools for their performances. First, The Plane [9] unified dance, theatre and computer media in a duo between a dancer and his own image. With more interactive features, Hand-Drawn Spaces [11] presented a 3D choreography of hand-drawn graphics, where the real dancer's movements were captured and applied to virtual characters. Such interaction coupled with real time computing were achieved in "The Jew of Malta" [10] where virtual buildings, architecture cuts and virtual costumes were generated in real time, depending on the music and the opera singer's position on the stage. More recently, Latulipe et al. conducted the Dance.Draw project, producing three different pieces over the course of the project. "A Mischief of mus musculus" features projected geometrical shapes linked to the dancers' motion. "Whispering to Ophiuchus" combined interactive and pre-programmed visuals. Finally, "Bodies/Antibodies" was a restaging of a modern

choreography, adding biological-themed visuals linked to gyroscopes and accelerometers on the dancer's body [6] [7]. In 2013, “Chiseling Bodies” was presented at the CHI conference. In this show, expressive qualities were extracted from a dancer’s movement and rendered as physical parameters for particle systems projected onto a screen on stage [1] [2]. In 2014 M.C. Pietragalla and J. Derouault, in association with the Dassault company, created *M. et Mme Rêve* [12], an immersive multi-screen (2D) dance performance featuring pre-recorded scenes and interactions.

All these performances feature on-stage interactions and projection (less often, augmented reality). Some performances focus on the visual atmosphere, techniques, and tools. In 2006 the grammy awards presented a duo featuring Madonna and the virtual band Gorillaz, using a special projection screen (the Musion Eyeliner [17]). In 2012 the performer and producer Steven Ellison (a.k.a Flying Lotus) produced the music show *Layer 3* [14], which coupled live performance with projections from visual artists Strangeloop and Timeboy. The setup consisted of two screens: one at the front of the stage and another at the back, allowing for the illusion of 3D projection as virtual objects could occlude the real performer. Finally, some artists focus on interaction. The French band Ez3kiel created several tangible interaction devices for their album “Naphthaline” (“Les mécaniques poétiques” – “Poetic mechanics”) to create music, making an exhibition the only way to truly enjoy their work [15].

As we can see, technologies are broadly explored at live performances. These shows are nearly always based on collaborative work, featuring both artistic and technical or scientific aspects. *Layer 3* [14], for example, is the result of the collaboration between a music performer and graphic designers. *Chiseling Bodies* [2] originated from research into the expressive qualities of movement. *M. et Mme Rêve* was born from collaboration between a dance company and an industrial company. Most productions focus on a technological keypoint (a tool, concept or technology), which artists seek to integrate in a coherent manner within their live performance. In *Layer 3* for example, the focus is on the dual screen, allowing the projections to surround the live artist. In *Chiseling Bodies*, the focus is on capturing the expressive features of movement. The visuals are kept simple: white particles on a black background. The particles move according to the dancer’s movements (e.g. expansion, quantity, etc). The simple aesthetics helps the audience to focus on the way they move and how they are linked to the dancer’s movements.

In *Debussy3.0* we sought to partially emulate these shows, merging interactive technologies and augmented reality for an artistic proposal. Our differences lie in the objectives that we set when creating the show.

## 1.2 Our objectives in *Debussy3.0*

Our goal is to explore the use of bodily interaction (using motion capture) and augmented reality (using projection on stage) in performing arts. In 2007 and 2008 we participated in the art festival *Les Ethiopiques*, producing improvised augmented dance shows in apartments [13] (figure 2). In 2011 we presented the show “CARE: staging of a research project” [4]. Our goal here was to demonstrate many of our tools and prototypes for interaction, emotion recognition and augmented reality that we developed during the CARE project (figure 3). Based on this experience and having reviewed what already existed, we refined our objectives for our latest project and show: the *Debussy3.0*

performance, which is presented in this paper. We defined four objectives for *Debussy3.0*.

First, we wanted to set up tools and techniques which are broad enough to allow long-term exploration, but also specific enough to be explored in depth. We focused on full-body interaction and stereoscopic 3D projections in a live performance since these techniques are new in performing arts, but still known and generally understood by the audience. Both fields are broad enough to create several shows: many interactions can be drawn using body movements with different visual aesthetics for 3D projection. They are also specific enough to be explored in depth with creations from several shows.

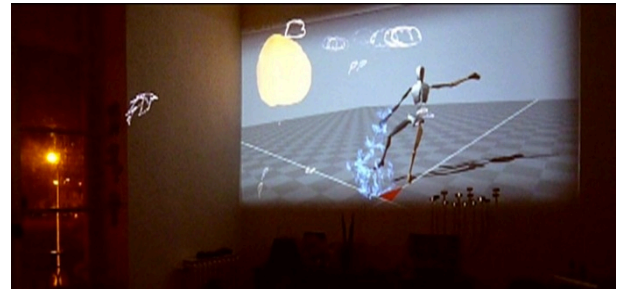


Figure 2. *Les Ethiopiques*, improvised augmented show in an apartment.

Second, we wanted to avoid the “gadget effect” of showing technology for its own sake. Focusing on body-movement as the input and 3D display as the output allowed us to better integrate these techniques as part of an artistic proposal. In particular, we aimed to make interactions clear for the audience. In 2011 we used many indirect interactions (e.g. emotion recognition), which were not understood by the audience, thus hindering the impact of the performance. Based on experience, we focused on direct movement interactions, where mapping between the input (movement) and output (reaction of a virtual element) is clear.

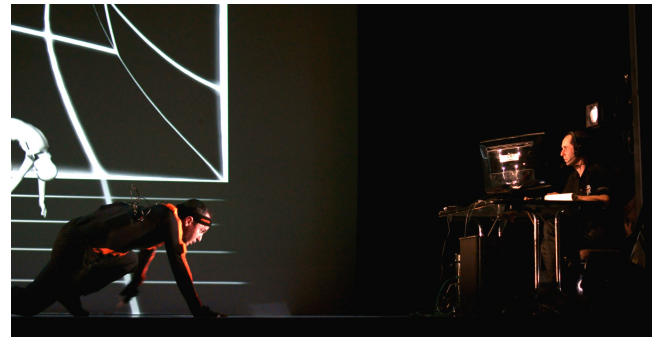


Figure 3. CARE, staging of a research project. On the right, the augmented reality engineer.

Third, we did not allow pre-recordings. Events occurring in the show had to be triggered manually. In particular, we did not want the dancer to be subject to rehearsal to synchronize with the virtual world. Music and movement drove the dancer, and all three drove the virtual world and its evolution during the performance. As this point is quite challenging, we introduced the role of augmented reality engineer (AR engineer). Like a light or sound technician, his role was to create the interactions and events in the virtual world (which in our case was created by a graphic designer). He was also in charge of interacting with the virtual world during the show. The dancer thus only performed

interactions that were consistent with the artistic proposal; additional tasks (e.g. triggering a specific event in the show's scenario) were left to the AR Engineer.

Finally, we wanted our physical system to be transportable. Our goal was not to produce a single show, but to explore bodily interaction and 3D projections in many shows with different artists. As such, our hardware system was easily transportable by car and was able to be set up in about half a day in a theatre.

## 2 DEBUSSY3.0: OUTLINE OF THE SHOW

In September 2013 we started working on the project *Debussy3.0*. Our goal was to integrate motion capture based interactions and stereoscopic 3D in an artistic proposal and offer a performance where these technologies would be a true part of the show, without overpowering it. We chose *La Mer* by Claude Debussy as our basis for music.

Six people carried out the project: two computer scientists, a graphic designer, a choreographer and two dancers.

### 2.1 Main themes of *Debussy3.0*

*La Mer* is a work divided into three parts, entitled “*de l’aube à midi sur la mer*”, “*le jeu des vagues*” and “*le dialogue du vent et de la mer*”. Our main theme is the parallel between man and nature (the sea), and man and technology. This parallel echoes the notion of the “digital ocean”, “the sea of information”... and the fact that we are facing a world where technology is more and more present. After the rise of computers, the democratization of the Internet and the rise of the smartphone, we now live in an always on world, surrounded by information. This evolution comes at a price as we are progressively losing our connections to nature. The three parts of *La Mer* reflect this evolution, as the man first faces the sea; then discovers it; and finally becomes part of it, completely surrounded by it.

This gradual evolution of the relationship between man and technology, and on the contrary, man's loss of his relationship with nature, is exemplified in *Debussy3.0* through the graphic design of each part, the staging of interactions and the choreography.

The performance's secondary theme is the *mise en abyme* of the staging. Through the performance, we seek to show the aesthetics of science and show the construction of the show within a show. Graphic design choices allowed us to hint at the construction of the 3D world and the development of interactions, thus showing what happened “behind the stage”.

### 2.2 Creating the choreography

In this section, we present the point of view of the project's choreographer.

*Debussy3.0* is the latest project in a long-term collaboration in which we redefined the expressive parameters of dance and movement within the frame of a constant interaction between the human and the machine. The sea, as a theme, acts as a new angle of reflection with regard to this interaction and questions our relationship with nature. If man can create and develop a relation with technologies, what is the role of nature in this interaction?

The position of man, between nature and technology, is the basis upon which the choreography is constructed. It follows the idea of a progressive dive in the sea that coincides with a dive into a digital world with its new technologies.

The two dancers, in *Debussy3.0's* scenography, are trapped between reality and virtuality. In the times of Romantic ballets, a performance was divided into two acts. The first act evoked reality, where dancers played peasants or princes, while the

second act addressed the unreality, where the dancers became ghosts. *Debussy3.0* features three parts, with the middle part acting as a bridge between reality and unreality. In the first part, the dancers act together. Step by step, the virtual world emerges; describing the sea and its abysses while an avatar appears. In that sense, *Debussy3.0* is a modern Romantic ballet, which evokes the fantasy that new technologies raised in their evolution. This fantasy follows the evolution of the relationship between technologies and their users up to the notion of immersion.

As *Debussy3.0* confronts us with new technologies, the choreography needs to highlight every possible interaction in order to establish a continuous and understandable link between the reality of the stage and the dancer's movement and the virtual world, while still keeping its relationship with musical aspects. The visual juxtaposition of the dancers and the projections is a challenge as it can easily confuse the spectator who then doesn't know where to look. The choreography was hence designed to smoothly bind the real and digital worlds in their dialogue with the music.

The form of the ballet is a *Pas de deux*, a duet where the female dancer is equipped with motion capture devices and can act on the virtual world, while the male dancer accompanies her in her dive into the digital world. The male dancer's movements are not captured. As such, he cannot act in the virtual world, instead providing the female dancer her only lasting link to nature.

### 2.3 Setting up the system

In *Debussy3.0* we focused on the use of full-body interactions and stereoscopic 3D augmentations. As such, our hardware and software setup can be described as a three-part line-up aimed at being reused for future shows (see figure 4). *Debussy3.0* is a duet; one dancer was fully equipped with motion capture sensors while the other was not captured at all.

We use an XSens MVN motion capture [17] suit for capturing the movements of a single dancer. The suit features 17 MEMS motion sensors (accelerometers, gyroscopes and magnetometers). The suit is thus resistant to occlusions and the uncontrolled lights of a stage. The MVN studio's commercial software computes the coordinates of the dancer on a dedicated computer (for reasons of robustness and processor load) and sends them over the network in real-time. A pre-recorded movement file of the dance performance was opened as a backup in case the MVN suit crashed in the middle of the show. We also used 5DT datagloves (5DT14U) [19] for capturing the dancer's finger movements.

We used Unity3D [20] for managing the virtual world (which was previously created by a graphic designer) and ran it on a dedicated computer with a professional graphic card. Initially designed for videogame production, Unity3D provides tools to easily manage our virtual set. Plugins are available to manage our input hardware and to perform stereoscopic 3D projection. In particular, the position of virtual elements can be controlled according to the physical screen, thus controlling the depth effect (elements located further than/behind the screen) and pop-out effect (elements located between the screen and the spectator).

We use two 8000-lumen projectors, with polarizing filters, for projection onto a 4mx6m screen, which proved enough for a 700-seat theater. Aligning the projectors for stereoscopy requires some time for fine-tuning. The 4x6m screen was actually composed of two 3x4m screens. These screens were special back-projection screens, which keep the polarization of light.

Apart from the screens, the whole system is transportable by car and can be set up in about half a day. The screens require a truck for transportation due to their length (4m).

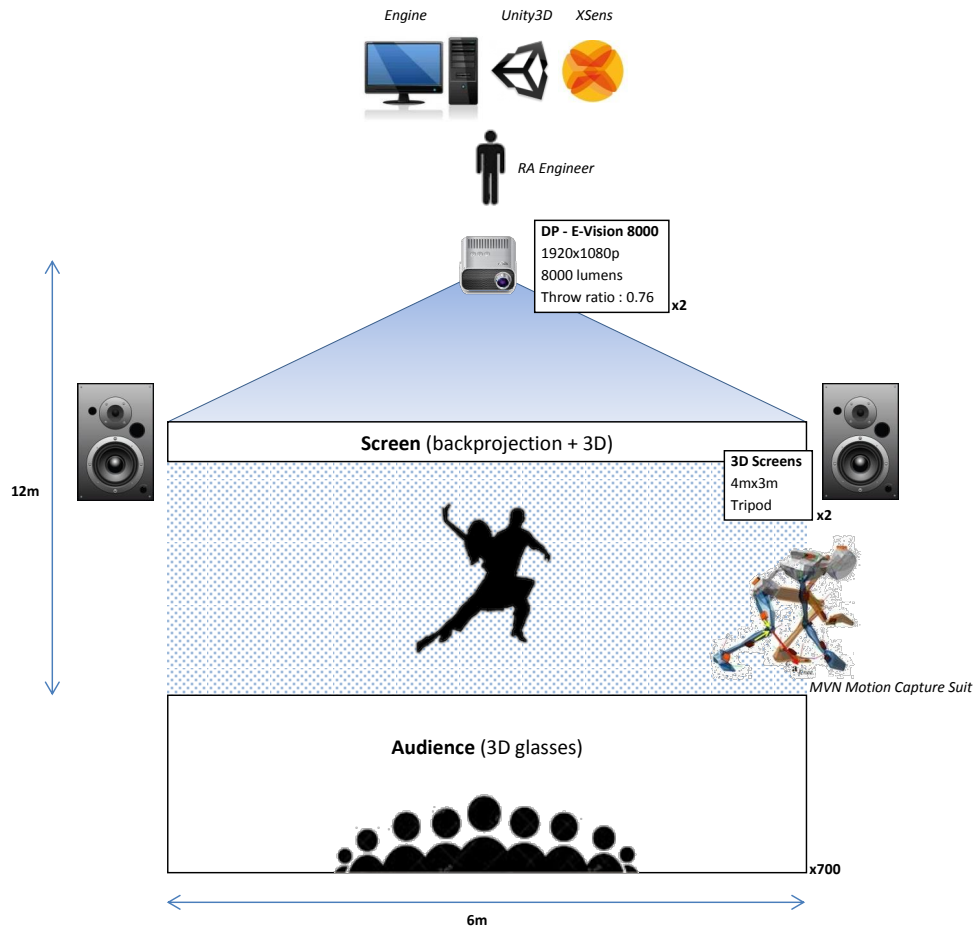


Figure 4. System setup for the stage.

### 2.3.1 Main interactions in the show

The show features several interactions. The equipped dancer performs the two main ones. Our goal was to make the relationship between the dancer's movements and the reactions in the virtual world as obvious as possible.

The first interaction consists of animating an avatar on the screen. The dancer's movement is copied by this avatar in 'real-time' (an approximately half a second lag occurs between the dancer and the avatar due to communication, processing and rendering).

The second interaction is surface generation by hand [5]. Following on from previous work inspired by Schkolne *et al.* [8], we use the line between the palm and the tip of the middle finger as a generating segment. Extruding this segment along the hand's path during movement allows 3D surface to be generated based on the hand's movement or 'trail'. We use the openness of the thumb as a modal interaction: when a thumb is closed, the dancer draws 3D strokes that seem to appear from the corresponding hand. When the thumb is open, movement is free and nothing is drawn.

The AR engineer also had some control over the virtual world. His main influence was with regard to using a 'blendshape effect'. The avatar consists of facets placed according to the avatar's skeleton. The blendshape effect allows each 3D facet to be moved away from its original position, creating the impression of an explosion (when the facets move away) or an avatar to be generated (when the facets revert to their original positions). This

effect is applicable in real-time and during movement. The AR engineer used a leapmotion [18] to control the distance of the facets from their original positions. When we originally viewed the performance, the AR engineer should have been visible by the audience and the use of the leapmotion induced a clear movement from the AR engineer, making it clear that this movement was the cause of the blendshape effect.

Finally, some basic interactions were also featured, allowing the AR engineer to control the performance rollout. The AR engineer could trigger scenario events (appearance of voluntary glitches for example) or modify some parameters (e.g. repositioning the avatar in the virtual world) using either a keyboard or a Microsoft Xbox gamepad.

### 2.4 Drawing the line: bridging technology and choreography through the use of aesthetics

Graphical design of the virtual world and the visual effects of the movement interactions play a central role in exposing our themes and bridging together the choreography and the interactions for the stage. The graphic design evolves according to the three parts of the show, outlining the progression of our main themes: the parallel between nature and technology, their relationship to man, and the aesthetics of technology. In the show, the female dancer is the only measured dancer and represents 'the man' in our subject. The audience, in front of the stage, is directly confronted with this relationship.



#### 2.4.1 Part 1: A realism which slowly crumbles

In this first part the dancer is still facing reality. She is facing the sea and the technological world without having really entered it. Progressively, this realism crumbles and reveals the illusion: the realistic scenery is a set that hides a digital world.

**Choreography.** This first part is a moment of meeting and preparation that progressively defines the intrinsic interactions between dance and music, between the two dancers, and between the dancers and the sea.

**Visual design.** The opening set is composed of video recordings of a sunset over the sea. This realistic scenery is voluntarily conventional (after all, the accompanying music is *La Mer – The Sea*). These video shots are however set on obviously irregular loops, hinting at a digital world. Progressively, the videos are subjected to glitches or video artifacts (“datamoshing”) that pop out of the screen with a light 3D effect, making the digital world invade the real stage (figure 5).

**Interactions.** In this part, the dancer is only facing technology but cannot act on it yet. Hence no movement interactions occur in this part. The appearance of glitches is controlled backstage by the AR engineer.

**Transition.** At the end of part 1, the glitched video folds, revealing that the sunset scenery was just a set and unveiling the digital world behind it in a transition to the second part of the show. The dancers leave the real world and enter a digital world.

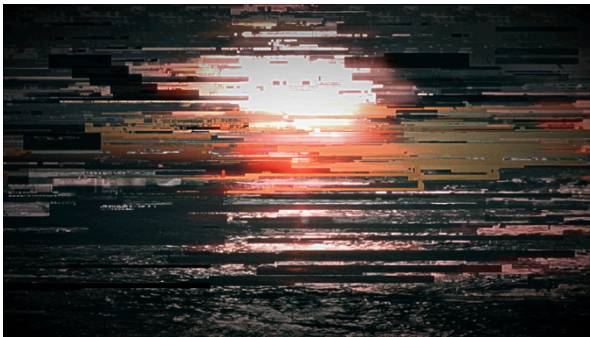


Figure 5. Virtual set screenshot from the first part. The video glitches gradually.

#### 2.4.2 Part 2: Diving into the digital world

In this part, the dancers dive into a clearly virtual world, but which retains some natural aspects. The construction of the virtual world is expressed through its own graphical design.

**Choreography.** The dancers, carried away by the music, get closer to each other and find themselves engulfed in a marine environment, which reacts to the female dancer’s movements. The projection begins to pop out of the screen, blurring the line between the real and virtual world.

**Visual design.** The second part of the ballet starts by diving from the surface of the sea towards the abyss. The set moves upwards as the dancer and the audience descends towards the bottom of the sea. The virtual set is populated with simple, geometrical shapes, resembling a lost engulfed city. The use of simple geometric shapes evokes the beginnings of 3D modeling. In the background, a giant geometrical structure shaped like a 3D grid reinforces this idea, as a reference to 3D grids in 3D modeling software (figure 6). The natural aspects of this part are expressed through beams of lights that come from the surface in at beginning of the dive. Later, when a certain depth is reached, particles float within the virtual world, just like when diving deep enough in the sea.

**Interactions.** In this part, the dancer discovers the digital world and begins to interact with it. Two interactions are featured. First, the dancer’s hands create trails that pop out of the screen. As the dancers dive, these trails move up the screen (see figure 6). As the dancer still does not have full control over the digital world, the AR engineer can also interfere with trail movements. Second, a 3D avatar gradually appears through a blendshape effect, copying the dancer’s movements. The 3D facets of the avatar are exploded at first, and then gathered together to form the avatar’s shape. The AR engineer controls this effect, playing with it at will during the course of the show.

Stereoscopic 3D is used for the whole virtual scenery, but is divided into two spaces. Most of the set is perceived as behind the physical screen, while only a few elements seem to pop out from it. The trails and the avatar seem to pop out from the screen, giving the impression that they exist in the same plane as the real dancers. We also made the particles in the water pop out, giving the impression that the whole stage is engulfed in water.

**Transition.** The dancers finally arrive at the bottom of the sea, which is pitch black with only a few popping particles. Far behind the stage, a shape is present. The set begins to move toward the shape.

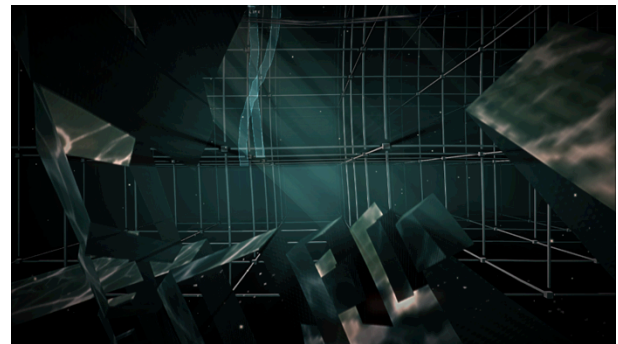


Figure 6. Virtual set screenshot from the second part. The blue trails are generated by the dancer’s hands.

#### 2.4.3 Part 3: the dancer as part of the digital world

In this part, the female dancer has lost her connection with nature and wanders into a purely digital world; the male dancer is her only link to nature.

**Choreography.** The dancers keep dancing closer and closer allowing the avatar to take more space and represent their movement within the virtual world. The avatar now creates the trails instead of the dancer, and transforms the space by sculpting a shape from its movement. The dancers are then brought back toward the surface and reality. Facing the sea, the dancers reflect on their encounter and their immersive experience in the virtual world.

**Visual design.** The shapes are purely geometric and ordered, forming a tunnel in which the avatar, the dancers, and the audience are propelled. The avatar is visible, exploded or constricted, and creates 3D surfaces (trails) with its hands. After a certain time, the tunnel ends and the gigantic, organic structure created by the trails throughout the performance appears on the screen, contrasting with the abstract geometry of the world (see figure 7).

In the last segment of this part, the dancers reenter the tunnel, to finally arrive at the sunset image from the first part: The cycle ends and they reemerge into reality after this strange journey into a digital world.

**Interactions.** In this part, the dancer is given full control over the generation of the trails. The dancer is a full part of the digital world. The AR engineer does not interfere.

**Conclusion.** The dancers face the sunset screen from the first part of the show. On the last notes of the music, they fall on each other. The show ends in sudden darkness. (*Noir*).

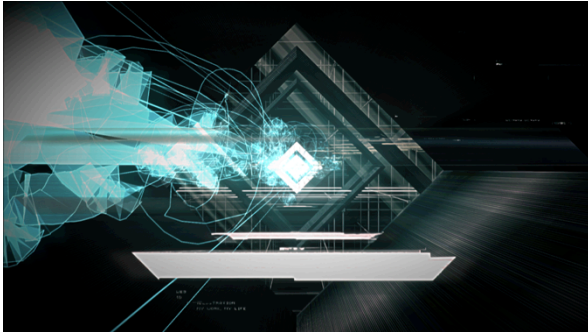


Figure 7. Virtual set screenshot from the third part. The organic structure created by the trails appears on the left.

### 3 FEEDBACK AND DISCUSSION

*Debussy3.0* was presented on December 15 2013 at the theatre of the Casino in Biarritz. The show took place on a Sunday afternoon and was free. We feared that ticketing would deter some people from coming, as Biarritz audiences are not accustomed to such kinds of shows. About 700 people came to watch the show. As we had underestimated the popularity of this premiere, we only had 400 pairs of 3D glasses, leaving about 250 people without glasses (some people had brought their own).

In this paragraph, we provide feedback about the show. After a short feedback session with our audience, we provided our own feedback on how we conducted the show and on the use of movement interaction and stereoscopic 3D when staging an augmented show, the mistakes we made and strengths we discovered when performing.

#### 3.1 General feedback from the audience

No hardware or software malfunction occurred during the performance. The audience was mostly a typical audience from the Ballet Company and employees from our university and the surrounding companies, i.e. mostly dance or technology-aware spectators. We gathered feedback from an informal discussion after the show, trying to assess whether we had fulfilled our objectives.

We received a very positive response from the people that gave us their feedback. All of them really enjoyed the show. The majority noted that the use of technology was well integrated and did not feel out of place. Interestingly enough, we also received this feedback from people who did not have 3D glasses. Novelty definitely played a role in their enthusiasm as they felt they were witnessing something new. Another factor is that although not able to truly enjoy the performance, they imagined the 3D when seeing the double images (left and right eye) on the screen. We also had very good feedback on the integration of the aesthetics of technology, as the obviously equipped dancer echoed the 3D visuals. As such, we attained our objective of integrating our technology within the artistic proposal and avoided the “gadget effect” that such technologies can have.

Although we focused on really simple mappings between the dancer’s movement and the reactions of the visuals on stage, our objective of rendering the interaction understandable was only

partially attained. Two spectators still thought that the movements of the avatar were pre-recorded. The half a second lag between the dancer’s movements and their repetition by the avatar (due to communication, processing, and rendering) was perceived as a lack of synchronization from the dancer with a pre-recorded video. This feedback was the exception. However the trails, originating from the hands, were generally blurrily perceived. In our opinion, this is mainly due to the AR engineer’s interference with their movement at their first appearance, creating an initial discrepancy that might be hard to overcome in the last part where the dancer fully controls the trails.

The use of stereoscopic 3D was generally very well perceived. It was noted that the show did not abuse the pop-out effect and that the use of 3D was light enough for a 30-minute show, keeping the audience comfortable. Here again, the “gadget effect” was avoided.

#### 3.2 Strengths and mistakes

From a technical and staging point of view, we identified two main issues concerning the performance and its perception by the audience.

##### 3.2.1 Hidden interactions

In our setting, the interactivity is shared between one of the dancers, whose movements are captured, and the AR engineer. The trail interaction was blurrily perceived by the audience as many of the spectators did not fully understand the link between the dancer’s movements and the creation of the trails. We identified one design choice that we believe caused this issue and a constraint that aggravated it.

First, the trail interaction was redundant between the female dancer and the AR engineer. The dancer’s hands controlled both the movement of the trails and their position in the virtual space. The AR engineer could, in the second part of the show, modify this position. Although interesting and consistent with the artistic proposal, this induces a staging problem. If the AR engineer is visible by the audience, as in our original design, then the AR engineer’s actions (movements with the leapmotion) divert the audience from the dancers. This case can be adequate if properly staged. In our case however, and due to physical space constraints on stage, we had to place the AR engineer backstage. His actions were hence hidden for the audience. This aggravated our issue, as the trails did not have a clear position related to the only visible action: the dancer’s movements. As a result, the audience just saw discrepancies in the trails’ position relative to the dancer’s movements, which impaired their assumptions on how the system worked and confused them.

We hence advocate that it is necessary to decorelate interactions performed by the AR engineer and by the dancer. If the AR engineer is hidden, then his interaction should be limited to global parameters of the digital setting (e.g. camera position, triggering events, etc). If the AR engineer is in full view, his actions should be perceivable by the audience. This was our initial goal: the blendshape effect (explosion of the avatar’s facets) was performed with an obvious gesture (using a leapmotion), visible from afar, instead of an action on a gamepad controller, for example.

##### 3.2.2 Use of Stereoscopic 3D in a live performance

The use of projected stereoscopic 3D raises an intrinsic technical issue: 3D is perceived along a Z-axis that originates from the point on the physical screen where the object is projected and terminates in the eyes of the viewer. While this issue is negligible with a small audience, it is a real problem in a large

theater. The perceived 3D space of a spectator in the right balcony will greatly differ from the perceived 3D space of a person in the left part of the orchestra. This is not a problem when watching a movie; however, in a live performance, this multitude of points of view can completely disrupt the intended spatial relationships between the virtual elements and the physical elements or the dancers. For example, the trails seemed to really originate from the dancer's hands only for a select few, well-placed members of the audience. The avatar also seemed a bit off for some people, lacking meaning in the spatial relationship with the real dancer. Although we had foreseen this effect and made the avatar move without reference to any point in space, it still disturbed many people in the audience.

A great strength of stereoscopic 3D however showed in the virtual set. Visual additions that reinforce immersion and have no spatial relationships with the dancers worked extremely well. For example, when the camera dives into the depths of the sea, we added some floating particles. These particles popped out of the screen. The effect worked marvelously as it gave the illusion that the whole stage (and for those at the back, even some parts of the audience) was underwater.

From this first on-stage experiment, we tend to think that apart from the obvious caution when using stereoscopic 3D (headaches, etc.), the use of pop-out effects should be restricted to ambient, environmental effects that have no spatial relationships with the real stage, setup and dancers (e.g. light glares, fog, stars, surrounding particles). Parts of the set that have a perceptual spatial relationship with the real stage should not pop out of the screen, but be perceived as being behind it as the spatial discrepancy is much less obvious in this case.

The multiplicity of points of view could even be turned into an advantage. Various artists have explored this issue. For example, Shigeo Fukuda, in his works *Duet* (see figure 8) or *Underground piano*, invites the viewer to watch the artwork several times in order to understand the complex construction that is being analyzed. The artwork is constructed according to the viewer's point of view. In a performance, this could be technically performed using the spatial augmented reality (SAR) paradigm. Physical objects would be set on the stage. Different visuals would then be projected onto their different facets, creating different objects for different points of view. An audience would then have different readings of the show, according to the spectator's seat in the theater.



Figure 8. Shigeo Fukuda's *Duet*.

#### 4 COLLABORATING BETWEEN ART AND SCIENCE

The *Debussy3.0* project had a secondary goal, which was to document, through the scope of the preparation and production of the *Debussy3.0* performance, the collaboration between ESTIA research laboratory and the National Choreographic Centre Malandain Ballet Biarritz (MBB). Since 2006 MBB and ESTIA have collaborated on several projects about bodily interaction and augmented reality in performing arts. Our first focus was emotion recognition through movement [3]. Dance was an application case

for our research, providing movement material for analysis and interpretation of an emotion expressed through danced improvisation. In 2007 we started using augmented reality as an artistic medium to convey the aesthetics of research with the CARE project [4]. After this project, we focused on simpler interactions, easily understandable by an audience. This led to the 3D painting project, where we allowed a dancer to paint virtual strokes in a 3D environment [5]. This work was reused in *Debussy3.0* in the form of the trails attached to the dancer's hands.

Art - Science collaboration differs somewhat from Industry - Science collaboration. Arts and science share some similarities, but also major differences that need to be overcome. Although the trend is changing, such collaboration is also often perceived as "useless", without a direct economic impact. In this paragraph we will present the difficulties of such collaboration, the similarities between the fields, and show the outcome and benefits in can bring to both parties, hoping this feedback might help scientists and artists seeking to establish such collaboration.

##### 4.1 The difficulties of collaborating

The first barrier that needs to be overcome between art and science is the need for common ground for dialogue. Research and artistic production are very different fields, with very different cultures and vocabulary. Establishing common ground for dialogue is hence the first step, which can take some time. One of the best ways to achieve this is to engage in the other party's activity (e.g. dance or development). The goal here is not to master the art but to grasp some of the partner's work culture and processes, which are then much better understood and complementary to theoretical readings.

This work on communication also helps overcoming typical misconceptions. Funnily enough, scientists and artists alike are all too often depicted in pop culture as "cryptic geniuses", hiding all the methodology, reflection and study of existing works, which is the basis of both art and science. The first danger this induces is to completely segment work, by fear or failure to understand the partner's field. We advocate that scientists should try to take part in the artistic process, while the artist should take part in the scientific process. The second danger of such misconceptions is that it induces either unrealistic expectations (e.g. "the scientist can build anything in no time"), leading to frustration, or hindering preconceptions (e.g. "the artist will not tolerate such and such a limitation of our system"), leading to a loss of time and effort.

A very efficient way to overcome these cultural limitations is to use a "proxy", a person who has both artistic and technical abilities. In *Debussy3.0* for example, the graphic designer acted as such a proxy, helping to translate the artistic proposal into interactions and technical specifications, and integrating the technical limitations within the artistic proposal, instead of being hindered by them.

The second barrier that needs to be overcome is the timing barrier. Research is a slow process, involving fund raising, prototyping, experimenting, analyzing data and publishing. This process can occur over years. Art, or at least dance, undergoes a quicker process, creating and producing a new performance over the course of just a few months. Adjustment is difficult. As such, research usually drives collaboration, providing established tools and techniques for arts to use. Arts can also take the lead, providing a time constraint that can be useful for quicker developments. In our experience however, we accommodated this time frame difference by keeping our collaboration as a part time

activity; this allowed the research laboratory to respect the usual research timing, while the artists produced shows unrelated to our collaboration.

Finally, we identified funding as a final barrier: both culture and research suffer from cuts in their funding, hindering collaboration.

## 4.2 Similarities between Art and Science

Collaborating between art and science proves difficult at times, but there are some similarities between the two fields, helping common work. Artists and scientists alike share a goal of novelty and originality in their work. Both rely on previous, existing work to place their work within a context and create something upon this. In this manner, artists and scientist share a passion for their field and work, which proves to be a great force. Finally, the goal of researchers and artists is not economic, but rather the dissemination of their work. In this way, communication is strengthened as it benefits from dissemination both from a scientific point of view (publications) and the artist's point of view (performances or installations).

## 4.3 The benefits of art-science collaboration

Art-Science collaboration, although sometimes difficult to trigger, can be greatly beneficial to both fields.

For scientists, art is often a field yet to explore, which can provide a perpendicular view on a research field. In our case, we first studied movement through the literature (mainly in psychology and computer science), which gave us academic knowledge in this area. Collaborating with dancers and choreographers allowed scientists to confront this academic knowledge with the personal findings of people who had dedicated their life to exploring their own movement, and eager to show us their findings through practice. For a researcher, this gives a complementary view of one's research area, and highlights some parameters not often found in the literature (e.g. the aesthetics of movement). Moreover, art as an application case can be very demanding, providing very specific needs and constraints that require the acquisition of specific skills or tools to be tackled. This leads to the acquisition of a niche expertise, which can then permeate toward other fields.

One of these constraints is the obligation to provide an error-free system. While a prototype is not an end-user product, its limitations should be clearly identified and potentially integrated in the artistic proposal. Unforeseen errors (hardware malfunctions or software bugs) can completely destroy the purpose of a system. In *Debussy3.0* for example, the choreography featured periods when the dancer would perform a particular position for recalibrating the motion capture suit if needed (as the loss of calibration was an issue we could not control). The system was however intensively tested to be sure no crash would occur during the show.

For arts, science is a new ground to explore, and a door to today's and tomorrow's world. In our case, our collaboration on interaction led the artists to go back to the fundamentals of dance, as the movement, instead of being directed toward an audience, had now to be directed toward both an audience and a machine. The use of augmented reality provides the ability to manipulate the set in real time and play with the rules that direct the stage. Specifically, augmented reality allows a visual persistence of movement, altering its ephemeral nature to offer a new vision of the choreography. It also allows the stage space to be extended and populated, giving more freedom (and at the same time, new constraints) for staging.

The final benefit is the multiplication of funding opportunities. While both research and culture may suffer a cut in their funding, a collaborative project can draw funds from either side (or both). In our experience, for example, we first conducted projects on national research funds, whilst *Debussy3.0* was entirely funded by cultural organizations.

## 4.4 Permeating research from art to industry

Our last point for advocating art-research collaboration is that the specificity of artistic constraints helps to develop a niche expertise that can permeate towards more industry-oriented projects. The skills and tools acquired within collaborative work can indeed be directly transferred to industry, or reapplied in other projects.

Several projects emerged from our collaborative work. Our first common research on movement analysis and emotion recognition is now used in ergonomics, for assessing the attainable zones and the comfort of a system operator (e.g. in a cockpit or for heavy machinery). Bi-manual interaction is currently featured in two industrial projects for engine maintenance and training in the construction industry. The passive stereoscopic setup that we assembled for *Debussy3.0* is demonstrated to local companies, and reused for building an immersive 3D room in our laboratory. This immersive room will be used in conjunction with movement and manual interaction to support our current research on natural movement-based interaction, and in a multidisciplinary project on creativity, innovation and creative industries.

## 5 CONCLUSION

In this paper we have presented our latest collaborative project: *Debussy3.0*, which ended with the premiere of the eponymous performance. The *Debussy3.0* ballet is an augmented, interactive performance, in which we explored movement interactions and the use of stereoscopic 3D as new tools for performing arts. Our goal was to focus on interactivity. To achieve this, we introduced the role of the augmented reality engineer, who designs the dancer's interactions and controls parts of the performance during the show. We had several objectives and were able to roughly assess their validation through informal feedback from the audience. First, we managed to integrate our tools and technologies within the artistic proposal, avoiding a "gadget effect" and showing technology for its own sake. Second, we managed to make the mappings between the dancer's movements and the virtual world's reactions clear to the audience, with a few exceptions. Finally, we were able to assess the validity of some of the techniques that we had presented, and discover some mistakes, notably in the use of stereoscopic 3D. The show was definitely a success, and we had very positive feedback even from spectators who did not have 3D glasses and thus could not perceive the 3D.

Our main feedback with regard to using interactions on stage is that they should be clear for the audience. The dancer and the AR engineer should not be able to perform the same task and, if possible, the AR engineer should be seen by the audience when manipulating the virtual world. This might change when the use of interactions in live performances becomes more common, but for now, too complex interactions only hinder the audience's understanding of the performance.

Our main feedback concerning the use of stereoscopic 3D in a live performance is to use caution when making virtual elements pop out of the screen. As with a real set, these elements define a spatial relationship with each other and with the dancers. Due to the different points of view in the audience, this spatial relationship greatly differs according to the seat occupied. Virtual



elements without a spatial relationship to the real world (such as environmental effects) should hence be favored, unless the difference of point of view is a key point of the artistic purpose.

Finally, we provided feedback on the long-term collaboration that we conducted as a research laboratory and a national ballet company. Our goal in this last section was to show that art-science collaboration can be highly beneficial, and doesn't exist for its own sake, as the gained expertise can permeate to other fields of study such as industrial ones.

Our perspective for this work is twofold. First, we wish to give more representations of the *Debussy3.0* show. Our goal here is to train in setting up the show, gain more insights in its strengths and weaknesses, and prepare the transition for creating an augmented performance company. Second, we want to show that the developed techniques and tools are not dedicated to large institutions. We are currently working on a show featuring two musicians, to be produced at a small venue. By gaining experience in such a way, we also aim to be able to set up more rigorous feedback-gathering techniques in order to better analyze the impact of technologies in live performances.

## 6 ACKNOWLEDGMENTS

The authors would like to deeply thank the dancers from MBB Irma Hoffren and Mickaël Conte for their dedication and performance. We would also like to thank the staff from ESTIA and MBB for their involvement in the project. This work was funded by grants from the French Ministry of Culture and the BNSA-Aquitaine Regional Department of Culture. Hardware investment was funded by the Aquitaine region (Sculpture Numérique project), the European project Transcreativa, and the PEPSS platform at ESTIA.

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