Augmented Stage for Participatory Performances

Dario Mazzanti
Istituto Italiano di Tecnologia
Via Morego 30
Genova, Italy
dario.mazzanti@iit.it

Victor Zappi
Centre for Digital Music
Queen Mary University of London
Mile End Road, London, UK
victor.zappi@qmul.ac.uk

Darwin Caldwell
Istituto Italiano di Tecnologia
Via Morego 30
Genova, Italy
darwin.caldwell@iit.it

Andrea Brogni
DreamsLab
Scuola Normale Superiore
Piazza dei Cavalieri 7, 56126
Pisa, Italy
andrea.brogni@sns.it

ABSTRACT

Designing a collaborative performance requires the use of paradigms and technologies which can deeply influence the whole piece experience. In this paper we define a set of six metrics, and use them to describe and evaluate a number of platforms for participatory performances. Based on this evaluation, the Augmented Stage is introduced. Such concept describes how Augmented Reality techniques can be used to superimpose a performance stage with a virtual environment, populated with interactive elements. The manipulation of these objects allows spectators to contribute to the visual and sonic outcome of the performance through their mobile devices, while keeping their freedom to focus on the stage. An interactive acoustic rock performance based on this concept was staged. Questionnaires distributed to the audience and performers' comments have been analyzed, contributing to an evaluation of the presented concept and platform done through the defined metrics.

Keywords

Interactive Performance, Evaluation, Augmented Reality, Mobile Devices, Music Control

1. INTRODUCTION

Interactive performances allow the audience to interact with the piece of work presented by a performer. Spectators may be able to access different aspects of the performance, as individuals or as a whole crowd. Access to the performance can vary in quality and quantity, and can include real time feedback given by the crowd to the performer, or direct control of audio and visual content by one or multiple participants. Research on specific interaction devices, techniques, mappings and proper interfaces is necessary, in order to provide the audience of such performances with the desired level and quality of control.

In this paper we define a set of metrics for the evaluation of concept and platforms used by interactive performances. Some existing solutions will be described and evaluated using these metrics. Starting from these premises and analyses, we propose a concept and platform for interactive musical performances, in which the audience can manipulate elements of Augmented Reality (AR) environments. Such AR elements are superimposed with the performance stage, generating an Augmented Stage. By interacting with AR elements using their own smartphones and tablets, the audience can access and control different aspects of the performance, while keeping a focus on the performance stage. The design and setup of the first performance based on the Augmented Stage concept is discussed. An evaluation of the concept main features is done through the analysis of audience experience, based on questionnaires and comments, and performers' feedback.

NIME'14, June 30 – July 03, 2014, Goldsmiths, University of London, UK.

2. APPROACHING INTERACTIVE PERFORMANCES

In the design of interactive performances, choosing a specific technology and interaction paradigm crucially affects the definition of the performance itself. While describing *The Interactive Dance Club*[13], Ulyate et al. listed out "10 Commandments of Interactivity". The guidelines encourage the design of an interactive venue where no cumbersome interfaces or instructions are needed. Participants do not need to be experts, so interaction must be simple but meaningful to the performance outcome. Interacting spectators should immediately understand the effects of their actions.

Recent studies introduced the use of the participants' mobile devices to provide them with access to interactive performances. Oh and Wang discuss different approaches to the use of mobile technology in participatory environments and performances [9]. The use of such devices can increase the involvement and gratification of large audiences within interactive setups. This application of audience mobile devices is in agreement with Ulyate et al. commandments, since it provides the participants with interfaces which are familiar, un-cumbersome and versatile.

As the study in [8] suggests, the emotional experience of an audience is positively influenced by the perceived connection between the performer's actions and the resulting output. In participatory performances, the transparency issue strongly applies to the relation between the audience manipulation and effects.

2.1 Metrics Definition

The mentioned studies and other research [10] inspired us in the design of 6 metrics, which can be used to describe

and evaluate technological and conceptual platforms used by participatory performances:

Control Design Freedom: How freely audience interaction can be designed with the platform.

System Versatility: Overall performance setting up simplicity and performer's comfort on stage.

Audience Interaction Transparency: Clearness of the relation between audience manipulation and its effects.

Audience Interaction Distribution: To what extent interaction can be located towards the participants (strongly centralized interface vs. every participant holds one).

Focus: How easily the audience can freely focus on different performance aspects (the stage, their interaction, visuals, music, etc.).

Active/Passive Audience Affinity: How much the non-interacting and interacting audience experience can be similar.

3. PLATFORMS AND EVALUATION

The metrics defined in Subsec. 2.1 are here applied to the evaluation of some platforms and concepts used by interactive performances. Each platform analysis is done based on available documentation, such as referenced papers, images or videos. Significant metrics of each platform will be mentioned. Complete evaluation schemes for some of the platforms can be found in Fig. 1.

3.1 Audience-driven Performances

Addressing large audience interaction, Feldmeier and Paradiso [4] created cheap radio frequency transmitters to be distributed to a virtually unlimited audience. Through sensors data, audience dance during a performance was mapped to different music parameters. *Audience interaction distribution* is high, since interaction is happening through each participant's sensor. The dance-triggered interaction implies a strong *active/passive audience affinity*. Participation depends on the sensors only, allowing the system to be used in any venue (significantly high *system versatility*).

The authors of *iClub*[11] created an interactive dance club application, allowing the guests of a dance venue to influence music playback of a computer-controlled DJ. Visuals are synchronized with the music, while audience interaction is provided by touch displays and physical devices (which allow high *control design freedom* and the design of *transparent audience interaction*). The platform can be extended with new modules (good *system versatility*).

The Interactive Dance Club (Ulyate et al [13]) consisted in a specifically designed interactive venue, where guests controlled projections, lights and music. Audience manipulation happened in interactive zones located throughout the club, each with a dedicated interface. Interfaces variety shows a high *control design freedom*, but *system versatility* is low, due to the complexity of each interface and to the fact that the stage was adapted to a specific venue. Since the installment forces the audience to move to each interface, the *audience interaction distribution* results low.

3.2 Mobile-based Performances

Mobile devices allow interesting approaches to platforms and interaction design. The *SWARMED* [6], *NEXUS* [1] and *massMobile* [14] platforms allow the audience to interact with live performances through browser based user interfaces, using their own mobile devices. This approach is enjoyable for participants, and versatile from a design perspective: by running on a browser, the interfaces don't need to be developed for a specific OS or device. The three platforms allow high *control design freedom*, *system versatility* and *audience interaction transparency*, and are obviously offering a strongly *distributed audience interaction*.

The *TweetDreams*[3] performance used real-time tweets to generate visuals and short melodies (low *control design freedom*, high *a/p audience affinity*), while the performers controlled how the tweets were musically and graphically rendered. All the mentioned mobile-based performances tend to attract the audience attention on their own devices during interaction, lowering the *focus* metric.

3.3 Performances based on other technologies

In the *dream.Medusa* audiovisual performance [12] four of the audience members where provided with accelerometer-based control devices (quite limited *control design freedom*). They manipulated visual aspects of the piece while standing in front of a projected screen, as the rest of the audience enjoyed the performance (low *a/p audience affinity*). The authors highlight how this kind of setup created a sense of responsibility and gratification in the participants.

The small audience of the Hybrid Reality performance *Virtual_Real* [15] interacted with virtual objects using passive markers for IR motion capture placed on their fingers. Nonetheless, *distribution* is moderate because interaction relies on tracking done within a specific stage setup, and *control design freedom* is partially constrained. Interaction was not mapped to audio features, but visually influenced the performance. The virtual environment was perceived as moving towards the audience and surrounding the performer, thanks to stereoscopic projection and Virtual Reality techniques (*focus* easy to distribute, since stage, visuals and interaction overlap).

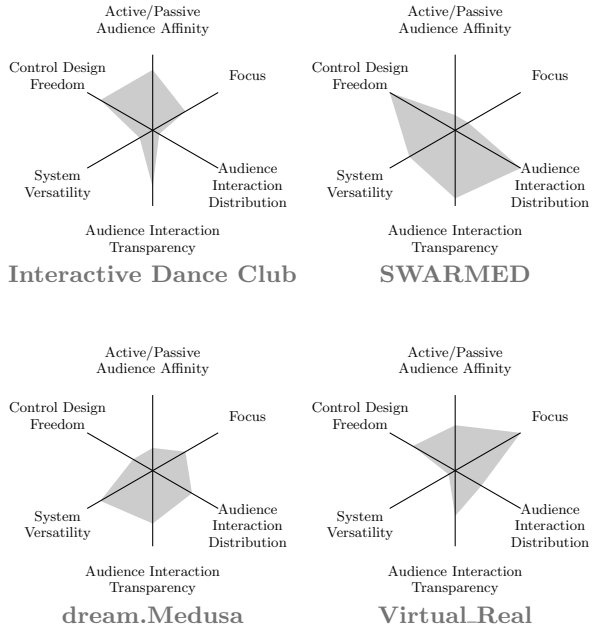

Figure 1: Interactive Dance Club, SWARMED, dream.Medusa and Virtual_Real platforms evaluation.

4. AUGMENTED STAGE CONCEPT

Starting from the observations of Sections 2 and 3, we elaborated a concept for the design and development of participatory performances, based on Augmented Reality technol-

ogy for mobile devices. Recent smartphones are powerful enough to provide enjoyable AR experiences, which allow interesting and novel interaction design solutions [5]. AR technology modifies the view of a real-world environment by superimposing virtual elements. This empowers the creation of interactive environments in which the manipulation of an enriched reality is possible. When the real-world view is watched through a camera feed, virtual elements can be visualized in correspondence to trackable images (AR targets) placed within a real environment. Previous work involving AR and music technology includes *YARMI* [7], a collaborative, networked, tangible musical instrument.

In our concept, the performance stage becomes an AR environment, which can be enjoyed through the cameras of the audience personal smartphones or tablets. Big posters placed on the stage act as AR targets, becoming part of the performance installment. The posters serve as placeholders for AR elements, characterizing the Augmented Stage. By watching the targets through the devices cameras, the audience can watch both the stage and the AR elements. Features of these AR objects are associated to visual and sonic controls. By manipulating these objects using their devices, spectators contribute to the performance outcome, together with the performers. A fixed camera is pointed at the stage, watching the performers and the posters. The feed of the camera is displayed, showing to the entire audience the Augmented Stage and the interactions taking place within it (Fig. 2). We expect the Augmented Stage concept to influence different experience aspects of interactive performances, from the point of view of the audience and of the performers.

4.1 Augmented Stage Platform

In the AR audiovisual platform we propose, the changes made to the Augmented Stage by someone in the audience are perceived by everyone, simultaneously and coherently. Based on these changes, the AR environment controls sonic and visual features of the performance.

A client AR application runs on spectators' devices, allowing them to visualize the Augmented Stage and interact with its elements. The mobile application connects to a server, which monitors the changes done to the AR environment by its clients. Whenever a change needs to take place, the server communicates it to all connected clients. The features of the Augmented Stage elements manipulated by the audience are mapped to audiovisual changes. The server codes these features manipulation into parameters, which are then streamed over the network, allowing external softwares to be controlled.

In our implementation, the server and the AR mobile applications were developed using the Unity3D game engine[1]. The AR capabilities where added by the Vuforia Unity3D extension[2]. This setup provides the tools needed to design and develop a shared Augmented Stage, its interactive visuals and the associated Android client applications. A computer running Ableton Live[3] receives OSC messages from the server through custom Max for Live[4] patches, and controls audio production based on changes happening within the Augmented Stage.

4.2 Audience's Experience

The use of AR in participatory live performances may improve audience experience in a number of ways. Some are strictly related to the nature of AR technology, while other are a consequence of its use in performances design.

AR tracking is done on the camera feed of spectators' devices, allowing them to enjoy the Augmented Stage from their personal point of view. To interact with each virtual object spectators may have to physically move, in order to put the desired AR target in their devices camera frame. Typically, 3D interactive environments do not provide this kind of experience, since the virtual environment is displayed on a shared screen, and from a single point of view. In our design, this still happens for the spectators who watch the Augmented Stage on the public screen, shown by the point of view of the fixed camera.

Since the stage augmentation is applied to the big AR targets placed near the performers, all members of the audience have visual access to what is happening on the stage, even when they are manipulating virtual elements through their devices, or watching them on the public screen. This is not possible with traditional on screen interfaces, which force the participants to focus their attention on the screen of a device in order to perform the desired manipulation, or to watch visuals on a display.

According to the performers' preferences, the controllable elements populating the Augmented Stage could be designed to enhance *audience interaction transparency*.

Performer's interaction transparency could also be enhanced, thanks to AR visualization techniques. This could be done by showing additional information on her/his mappings and interaction, as seen in Berthaut[2]. An increase in transparency can enhance performer's gestures expressiveness, as well as the liveness of the whole performance as perceived by the audience.

In order to access the AR environment, spectators need to install a specific AR application, and connect their device to a wireless LAN. The device needs to be suited to run the AR application. This represents the only limit to audience active participation.

4.3 Performers' Experience

In our concept, audience access to controllable content is completely provided by spectators' devices. This opens interesting possibilities for the performers to experiment with, when deciding which aspects the audience may control, and how. It has to be noted that by granting the audience a direct access to the production of audiovisual content, the performers accept to introduce a potential element of distraction. The unpredictability of the audience contribution, especially in the sonic domain, could result in an increased difficulty to perform the live act. On the other hand, a significant audience contribution may provide the starting point for the creation of ever-changing performances, stimulating their creators in new ways, and providing them with a unique experience. Still, these effects strongly depend on each performance design choices, and are independent from the Augmented Stage concept itself, which is conceived for design flexibility.

5. CON I PIEDI PER TERRA

con i piedi per terra is the first participative musical performance based on the Augmented Stage concept. The performance was designed in collaboration with *il GRANDENERO*, an acoustic rock duo. It was presented to the invited audience as an interactive musical event, in which the spectators were given the possibility to conduct part of the music by exploring a virtual environment through their Android mobile devices.

The stage setup was rather simple (Fig. 2), and based on the platform described in Subsec. 4.1. Three A0 for-

[1]http://www.unity3d.com/
[2]https://www.vuforia.com/
[3]https://www.ableton.com/
[4]http://cycling74.com/products/maxforlive/

Figure 2: *con i piedi per terra* stage. AR interactive elements can be seen on the projected screen. On the right, the performers are playing and AR targets posters can be seen behind them.

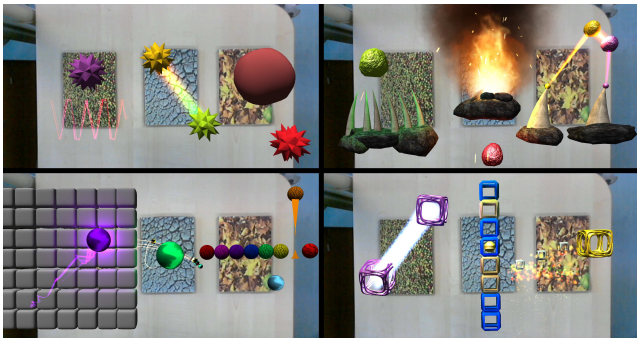

Figure 3: The interactive objects used for the performance are here superimposed with smaller scale test AR targets.

mat posters were distributed horizontally at 2.15 meters one from another, and hung on the rear wall of the stage. The posters acted as AR targets, and were clearly visible. Their placement left two empty spaces among them, to be occupied by the performers during the live act without covering the AR targets. This setup allowed the interacting audience to watch the AR environment while also watching the stage and performers.

A small table behind one of the performers hosted a multitrack audio interface and 2 computers: the first one ran the Augmented Stage server, and the second one Ableton Live. On the roof of the venue, pointed at the stage, a Full HD Logitech C920 webcam was installed. Its video feed was processed by the server in order to show the stage augmentations to the whole audience, on a portable projection screen placed on the left side of the stage. This allowed also the non-participatory audience to watch the Augmented Stage and the interactions taking place within it. A wireless router hosted a LAN to allow the communication among the two computers and the connected audience devices.

5.1 Performance Design

During the performance, *il GRANDENERO* played four tracks from its existing repertoire. In addition to the duo usual instrumentation (two guitars and a lead voice), new arrangements were written to be played by Ableton Live during the performance, and controlled by the audience. Before the beginning of each song, musical transitions were played by the computer. These intermissions were written using exclusively the audience-controllable instruments accompanying the upcoming track. This allowed the spectators to explore the controls of each track on their own, right before using them together with the band.

Each track provided three different audio channels to be controlled by the audience, one for each AR target. Depending on the instruments and effects present on a specific channel, one or more of their parameters were exposed for audience control. Each parameter was chosen so that its effect could be easily perceived by the spectators as a consequence of their interactions.

The audio parameters were mapped to features of AR virtual objects shown in correspondence of the stage posters. The simplest mappings, using only one parameter, associated the position of AR objects to audio synthesis continuous controls, for example the distortion of a bass synthesizer or the frequency of an LFO. More complex mappings included a sequencer-like tremolo pattern programmer and a discrete delay beat selector, using up to 10 parameters.

Interaction with AR objects happened through the mobile devices touchscreen (Fig. 4): some elements could be dragged with a finger, other behaved like on/off buttons, while other required the touch of multiple spectators at the same time, in order to produce a stronger feedback. AR objects and elements where visually designed according to each track aesthetic theme (Fig. 3). The manipulation of AR controls also influenced the visual behavior of AR objects, which resulted in simple choreographies.

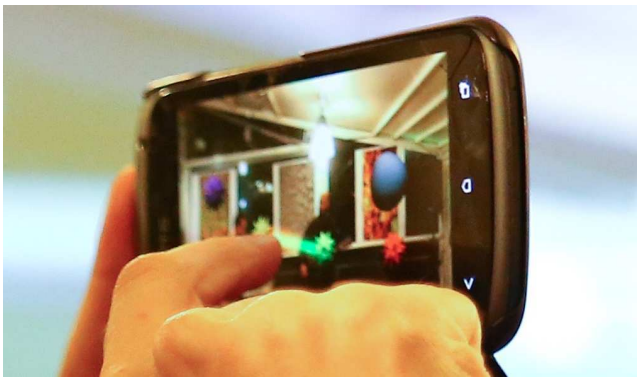

Figure 4: A participating audience member manipulates music by interacting with AR elements. The whole stage can be seen through the device camera.

AR controllable elements were not available for the whole duration of each track. In fact, they appeared and disappeared in different combinations, based on pre-programmed patterns. Controls of the first track were available only during the track outro and preceding intermission. The alternation of participatory and non participatory moments was introduced both as a performance design choice, and as a cue to highlight the difference between controlling the additional arrangements and only listening to them.

During the whole concert, the audience could watch the Augmented Stage on the projected screen, shown from the point of view of the ceiling mounted camera. Non interacting spectators thus enjoyed a shared view of the Augmented Stage, while the interacting audience had an additional way to verify when interaction was available.

Before the concert, a tutorial track was played to introduce the audience to the interaction paradigms, and to verify that their devices were working properly. The spectators were kindly asked not to monopolize the controls throughout the performance. More structured strategies like time limits or turns were avoided: based on first-hand experience with other performances, we think such solutions induce the participants to perceive interaction as a game.

6. EVALUATION

con i piedi per terra was attended by 25 spectators. After the concert, questionnaires were given to receive feedback on the audience experience. The surveys were composed by statements, to be evaluated in terms of agreement level with numbers from 1 to 7 (1: "I totally disagree with this statement"; 7: "I totally agree"). The 9 attendees who interacted with the Augmented Stage received a set of 18 statements. The 16 spectators who did not interact received 16 different statements. Topics touched by the statements addressed the metrics defined in Subsec. 2.1 and other aspects. Blank space was left on the questionnaires for personal comments.

6.1 Questionnaires

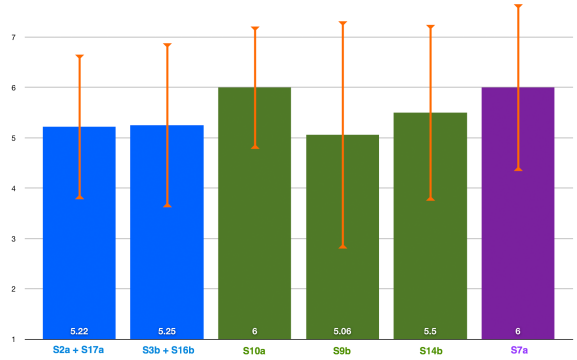

Figure 5: Audience agreement average values and standard deviation for sentences addressing *audience interaction transparency* (in blue), *focus* (in green) and device setup simplicity (in purple).

Some of the data extracted from sentences agreement can be seen in Fig.5. Based on a 5.22 average agreement score of statements S2a and S17a of *interacting* spectators questionnaires ("The virtual objects manipulation I did was connected to the sounds I heard"; "During interaction I was understanding my contribution to music"), *audience interaction transparency* was good, but probably the association between some AR elements manipulation and their sonic effect was unclear. A spectator noted in the free comments section that "Audience sonic actions were not evident enough, compared to the performance sounds", probably addressing a volume mixing problem which partially affected the performance (some volumes had to be raised halfway through the concert). Consistently, the *non interacting* spectators agreed with an average 5.25 in saying that "It was clear when the spectators were interacting" (S3b) and that they "managed to understand what the devices of interacting spectators were used for." (S16b).

Generally, *focus* was perceived as easy to distribute between the stage, the music and the interactive visuals, from both *interacting* and *non interacting* attendees. In particular, *interacting* spectators statement "The device camera allowed me to interact and follow the performance at the same time" (S10a) was given an average agreement score of 6, with only two evaluations below 6, one of which was commented by the note "I was actually not distracted visually, but only from the music". This suggests us that the superimposition of virtual controls and stage video feed helps the audience in keeping a focus on the performance elements. Also, other statements evaluations suggest that the *non interacting* audience found the projected content to increase their interest towards the performance, but did not completely distract them from the real stage.

The personal devices setup was considered quite simple: S7a statement, "The setup of my device required a short time and/or was a simple operation", received an average agreement score of 6.

Even if the desire to be part of the *interacting* audience was evaluated with an average score of 5.56, different aspects of the performance were well received by the *non interacting* audience as well. They found their own involvement in the performance was quite strong because of the presence of an *interacting* audience (S1b, average agreement score 5.31), and the projected screen contributed in making the performance more interesting (Q6b, average agreement score 5.63). Together, *interacting* and *non interacting* spectators evaluations generated an agreement score of 5.97 when describing the performance as different from previous attended installments.

Other sentences response highlighted an overall positive experience. One of the *interacting* participants left an "I ROCKED!" note in the middle of the questionnaire, while another participant expressed the desire to "have some more objects". The two comments address the topic of reward in participatory performances, showing that audience interaction was rewarding, but some participants desired more quantity or variety in interaction. Another participant underlined enthusiasm towards the performance, saying that he can not play any musical instruments, while the AR controls gave him the possibility to play music during a live act.

6.2 Performers' Feedback

The performers found the experience stimulating and creatively challenging. They preferred the audience to manipulate computer-timed arrangements, so their usual setup was slightly changed to support this specific choice. The only significant constraint was that of not covering the posters too much with their bodies, but their usual on-stage act and presence was kept unvaried. One of the performers stated that "It was challenging to play while they [the interacting audience] changed all the musical references I had during rehearsal". Later, he added that he would like to repeat the experience, organizing rehearsal sessions in which a selected audience participates to help the performers getting used to unexpected changes in the music. The suggestion made by the performer underlines how musicians, dancers and actors who are new (as the performer was) to participatory live acts may be used to mistakes and changes happening on stage, but not to significant contributions coming from the audience. Nonetheless, it addresses an issue which is not specific of the Augmented Stage concept, but potentially touches all platforms for participatory performances.

6.3 Augmented Stage Concept Evaluation

Following the approach used in Sec. 3, we present an evaluation of the Augmented Stage concept and platform. The evaluation relies on the metrics defined in Subsec. 2.1, and takes advantage of the analysis done on *con i piedi per terra* in previous Subsections.

Audience interfaces are strongly *distributed*, being placed exactly in the participants' hands. The AR interfaces allow a high *control design freedom* and *audience interaction transparency*. The overlapping of stage, virtual environment and interaction facilitates the *focus* distribution, by not hiding the performance aspects from the audience's eyes. Questionnaires data analysis suggests a satisfactory *a/p audience affinity*. The mobile devices setup was considered simple by the audience. No complex technology is required to setup the stage, and the platform allows performers to choose to which extent modify their setup and habits. This makes the concept suitable for most venues and performers (*high system versatility*).

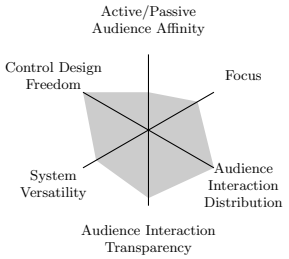

Figure 6: Augmented Stage concept described by the participatory performance evaluation metrics.

7. CONCLUSIONS AND FUTURE WORK

We defined a set of metrics to evaluate platforms for participatory performances, and analyzed some existing solutions using such metrics.

Consequently, the paper presented the Augmented Stage concept and platform for participatory audiovisual performances, based on AR technology. In our concept, members of an audience can perceive virtual objects superimposed with the performance stage, through their mobile devices camera. AR elements populating the stage can be manipulated by the spectators to control visual and sonic feedback. The Augmented Stage can also be watched on a public display through a fixed camera pointing the stage.

An interactive musical performance based on the presented concept was staged: through personal devices, part of an audience manipulated different sets of AR objects of an Augmented Stage, modifying electronic music arrangements while an acoustic rock duo was playing. After the performance, questionnaires given to the audience and collected comments allowed the evaluation of different performance aspects. General response was strongly positive, with many attendees expressing the desire to repeat the experience, and the performers interested in the further exploration of the concept potential.

The Augmented Stage platform was then evaluated using the previously defined metrics. The platform provides the freedom to design different kinds of choreographies and interactions, coherently with performances style and purpose. The simplicity of the setup permits to stage performances in most venues. The use of spectator's personal devices allows the design of transparent and powerful audience and performer interactions, contributing to the generation of ever-changing performances. This kind of experience increases audience reward and contribution awareness. AR could improve the transparency of the performers' actions as well. The concept of Augmented Stage can be applied to all performing arts, including music, theater and dance.

The positive feedback received through comments and questionnaires encourages us to continue the study and development of the Augmented Stage concept, also through the design of new performances. It is our intention to investigate the potential of visual elements to affect *audience interaction transparency*, and to invest our efforts in testing the concept with larger audiences.

We are also interested in developing the performer side of the Augmented Stage concept. Smaller copies of the AR targets could be placed in front of the performer, who could explore the AR environment with a personal device, and use it as a DMI to access additional mappings. The device may give visual information about the stage and interaction, provide simple haptic feedback through vibration and help to monitor spectators' interaction, with no need for additional visualization channels. As a further exploration of this development, bigger targets could be installed behind or among the audience, to create a new, performer-centered AR experience, also enjoyable by the audience on a display.

8. REFERENCES

[1] J. Allison, Y. Oh, and B. Taylor. Nexus: Collaborative performance for the masses, handling instrument interface distribution through the web. In *Proceedings of the Conference on New Interfaces for Musical Expression*, 2013.

[2] F. Berthaut, M. T. Marshall, S. Subramanian, M. Hachet, et al. Rouages: Revealing the mechanisms of digital musical instruments to the audience. In *Proceedings of the Conference on New Interfaces for Musical Expression*, 2013.

[3] L. Dahl, J. Herrera, and C. Wilkerson. Tweetdreams: Making music with the audience and the world using real-time twitter data. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, 2011.

[4] M. Feldmeier and J. A. Paradiso. An interactive music environment for large groups with giveaway wireless motion sensors. *Computer Music Journal*, 31(1):50–67, 2007.

[5] M. Gervautz and D. Schmalstieg. Anywhere interfaces using handheld augmented reality. *Computer*, 45(7):26–31, 2012.

[6] A. Hindle. Swarmed: Captive portals, mobile devices, and audience participation in multi-user music performance. In *Proceedings of the Conference on New Interfaces for Musical Expression*, 2013.

[7] T. Laurenzo, E. Rodríguez, and J. F. Castro. Yarmi: an augmented reality musical instrument. In *Proceedings of the Conference on New Interfaces for Musical Expression*, 2009.

[8] M. Marshall, P. Bennett, M. Fraser, and S. Subramanian. Emotional response as a measure of liveness in new musical instrument performance. In *CHI 2012 Workshop on Exploring HCI's Relationship with Liveness*, May 2012.

[9] J. Oh and G. Wang. *Audience-participation techniques based on social mobile computing*. Ann Arbor, MI: MPublishing, University of Michigan Library, 2011.

[10] S. Reeves, S. Benford, C. O'Malley, and M. Fraser. Designing the spectator experience. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 741–750. ACM, 2005.

[11] J. Samberg, A. Fox, and M. Stone. iclub, an interactive dance club. In *ADJUNCT PROCEEDINGS*, page 73, 2002.

[12] R. Taylor, P. Boulanger, and P. Olivier. dream. medusa: A participatory performance. In *Smart Graphics*, pages 200–206. Springer, 2008.

[13] R. Ulyate and D. Bianciardi. The interactive dance club: Avoiding chaos in a multi-participant environment. *Computer music journal*, 26(3):40–49, 2002.

[14] N. Weitzner, J. Freeman, S. Garrett, and Y. Chen. massmobile–an audience participation framework. In *the International Conferences on New Interfaces for Musical Expression (NIME)*, 2012.

[15] V. Zappi, D. Mazzanti, A. Brogni, and D. Caldwell. Design and evaluation of a hybrid reality performance. In *Proceedings of the 2011 conference on New Interfaces for Musical Expression*, pages 355–360, 2011.