On Designing, Composing and Performing Networked Collective Interactions

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In this article, we discuss some of our research with Local Area Networks (LAN) in the context of sound installations or musical performances. Our systems, built on top of Web technologies, enable novel possibilities of collective and collaborative interaction, in particular by simplifying public access to the artwork by presenting the work through the web browser of their smartphone/tablet. Additionally, such a technical framework can be extended with so-called nano-computers, microprocessors and sensors. The infrastructure is completely agnostic as to how many clients are attached, or how they connect, which means that if the work is available in a public space, groups of friends, or even informally organised flash mobs, may engage with the work and perform the contents of the work at any time, and if available over the Internet, at any place. More than the technical details, the specific artistic directions or the supposed autonomy of the agents of our systems, this article focuses on how such *'networks of devices'* interleave *with the 'network of humans'* composed of the people visiting the installation or participating in the concert. Indeed, we postulate that an important point in understanding and describing such proposals is to *consider the relation between these two networks*, the way they co-exist and entangle themselves through perception and action. To exemplify these ideas, we present a number of case studies, sound installations and concert works, very different in scope and artistic goal, and examine how this interaction is materialised from several standpoints.

1. INTRODUCTION

The 2020–21 COVID crisis has brought the *network* sharply into focus as a major topic in the music community, not only as a tool for communication but also as way of seeking novel approaches to rehearsal and performance. It might thus seem opportunistic to develop concepts and discuss network-related music practices, and while we acknowledge that the current situation offers us a new perspective, our explorations in this area started several years ago and all reported experiments and situations were developed before the 2020–21 COVID restrictions. Nevertheless, we will discuss at the end of this article how the new situation puts this research in a different light.

The aim of this article is to articulate several concepts and methodologies around the 'network' we co-created with a diverse group of individuals, artists, performers and researchers. Interestingly, these projects were designed in co-located spaces, that is, in a shared physical space with all the participants present.

Additionally, while our research over the years has implied development and experimentation with several technologies, and while we will briefly introduce our technological stack, technology is not the focus of this article. Of course, we acknowledge the influence of a large body of works on using networks in music practices (Bischoff, Gold and Horton 1978; Gresham-Lancaster 1998; Levin 2001; Weinberg 2005; Turchet, Fischione Essl, Keller and Barthet 2018). In this article, fundamentally sharing with Small (1998), the idea that music practices are collective endeavours, including a large set of persons actions, from ideation, creation, production, performance, listening and their myriad interdependencies, we propose here to consider networks from a much larger perspective.

As an extension of the notion of *musicking* (Small 1998) and as a way of clarifying the interdependencies suggested previously, we consider our work is best described as a network of actors, to be understood as a heterogeneous and evolving mix of persons, objects and technologies, instruments and mediation techniques that cannot be either simply understood as a linear evolution of various research and artistic practices or organised hierarchically. Therefore, as a sort of 'mise en abyme', we will invoke Actor-Network Theory (ANT) to elucidate the practices and processes we are referring to (Latour 1996).

To this extent, one might consider that the broader notion of 'Network' is an emergent property of the infrastructure, the creative process, the actors within the network, the devices attached to the infrastructure and the cumulative actions facilitated by this community in making music in real-time. The notion of network is then expanded beyond the technical infrastructure to become a sociocultural assemblage. Another characteristic of this assemblage is that it

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exposes emergent properties, which while they may be constrained through compositional parameters are nevertheless not predetermined in their enaction. These emergent properties give rise to musical creation that has critical differences to previous musical composition and performance paradigms. Through their non-linearity, these assemblages may connect different sociocultural contexts, time, space, place and causality.

Interestingly, these assemblages reverse to some extent, Emmerson's acousmatic dislocations. Emmerson (1994: 95) argues that the 'truly fundamental acousmatic dislocations occurred in the half century to 1910:[1] Dislocation 1: Time (recording), Dislocation 2: Space (telecommunications (telephone, radio), recording), Dislocation 3: Mechanical causality (electronic synthesis, telecommunications, recording)'. One can think that the network even reinforces these dislocations, by separating each type of sound processes. However, if we look at the network as an assemblage, directed towards music-making, it also complexifies each of these dimensions, by creating interactions between the associated processes. The network as musical assemblage presents itself as a dynamic platform, potentially ubiquitous (beyond space), without musical form or the fixedness of a specific concert structure (beyond time), omnipresent to all participants, with potential for collective endeavours: assembling persons, actions, ideation, creation, production, performance and listening.

Our hypothesis is to consider that the network has particular material properties that can lead to re-question and possibly reinvent traditional musical boundaries and hierarchies. For instance, in a performance where elements of the composition are being performed on the audience's smartphones, the hierarchy of audience–performer can be reimagined as a rhizomatic structure (Deleuze and Guattari [1980] 2004), whereby all individuals are critical to and partaking in the performance of the work. As we will discuss, this reframing of the performance environment can lead to proposing different types of people engagement, potentially including all individuals present, while everybody remains free to choose their type or level of participation. The notion of virtuosity is therefore also partially deconstructed, as the embodied engagement of the audience members in the performance transforms them from a passive listener to an active agent of creation. Furthermore, when sound is originating out of the personal smartphone of the audience member, and is therefore also physically within their proximity, there is a sense by which the audience member directly embodies the performance through investing in its creation.

[1]From 1860 to 1910.

Our goal in this article is not to organise such links and actions, avoiding on purpose the description of a complete taxonomy or reducing projects to mere 'artistic intentions', but, on the contrary, to make evident emergent common patterns, as much as differences, in using networks in musical settings.

2. ON NETWORK TOPOLOGIES

In a recent review of some of our research prototypes, we introduced the notion of interaction topologies (Matuszewski, Schnell and Bevilacqua 2019). Starting from the point of view that music is a collective experience, occurring either as co-located or dislocated in time and space, some of the research effort has concerned the design of mediation technologies (Leman 2007). As stated earlier, in the context of this article, collective experience is understood as a series of 'actions' emerging between human and non-human 'actors' (to be understood as in the Actor-Network Theory).

The use of web technologies, as a means to investigate these relations between all these actors, is critical in many of the discussed projects because each audience member has a device in their pocket that can communicate over a network, as well as generate, receive and display information and media through a web browser. This choice means that no additional application needs to be downloaded to the audience member's device, which may not have sufficient free space, or the user may not accept the possible security risk. It also means that the bar for access is minimal as all phones/tablets have a web browser and can connect to Wireless Local Area Networks (WLAN) through Wi-Fi.

For the purpose of the works discussed in this article, a dedicated 'Local Area Network' (LAN) is often created as a wireless local network that is not connected to the outward facing internet. These 'technological networks', considered as mere tools, are used in order to contribute to our interaction design aims. Importantly, there is a meaningful mismatch between the actual 'technological network' links and nodes and a more global network describing the complete map of interactions that could be described as a 'perceived network' among the actors.

This is of course similar to what happens when interacting with communication technologies, which succeed in making the physical information transmission invisible to the user(s). For example, exchanging messages with another person is perceived as a two-person interaction. The segmentation of the signal into packets travelling through several servers, maybe taking non-trivial routes, is hidden and unperceivable to the users. Only the general transmission quality might be perceived, but no agency is provided to understand

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where physically in the world the bandwidth bottleneck may be. At best, an informed guess, based on knowledge and experience can provide an answer.

This gap between the physical communication network and the perceived network of interaction is important and must be fully recognised. As researchers or artists (or both) in music, we have unique opportunities to act on both levels using our own built system(s), creating creative ecosystems that may not be possible with commercial, closed solutions. We design and create networks and interaction considering both perceptual (experience) and technical points of views. Thus, two types of network *topologies* should be considered: the technological ones and the ones describing the human/communal experience. The technological network does not represent a goal in itself, it *is only developed* and set up to enable musical experience. This experience is the result of a complex set of interactions between humans, objects and sound. The complete topology of such an experience is mostly an emerging property, based on a set of material, rules and human (action-)perception. Several experimental stages are necessary to observe and grasp the full emerging properties, constantly making adjustments at various levels, human and technological.

3. EXAMPLES

The following examples presented all rely on a technological framework, which originates from a collaborative project with several institutions called *CoSiMa*[2] and which enabled us to develop collaborative and collective interaction based on mobile and web technologies (Robaszkiewicz and Schnell 2015). The formats we explore include interactive sound installations, augmented reality experiences, participatory concerts, flash mobs and collective performances.

The possibility to use web standards such as HTML/CSS, Web-Sockets, Web-RTC, Web-GL, Web Audio API as well as Geolocation, DeviceOrientation and DeviceMotion enable implementation of complex network systems, which can be deployed either on local networks or on the internet. Precisely, the deployment of prototypes and pilots as web applications allows for instantaneously publishing applications worldwide as well as for very rapidly setting up experiences on local networks, inviting audiences of virtually any size to participate. More recently, this technological framework has been generalised to gather large ensembles of mobile and embedded devices, such as smartphones/tablets, microcontrollers and nano-computers (e.g., Raspberry Pi) (Matuszewski 2020b).[3] Importantly, it also exposes the possibility of sharing a common clock and thus synchronise these heterogeneous devices, which is of particular importance for several music contexts (Lambert, Robaszkiewicz and Schnell 2016). Various developed open-source *JavaScript* libraries have been expanded beyond the initial *CoSiMa* project and are currently available.[4]

3.1. Future Perfect

Future Perfect[5] by Garth Paine is a work that utilises the loudspeaker of networked devices to create an audience–performer role as a loudspeakers/sound generation device within an ecosystem. In this work, listening and perceiving the quality of the communally generated sonic ecosystem is prioritised over physical interaction through gesturing with the device.

The audience's use of their smartphones binds them into the ecosystem of the performance. Sound is performed directly on their phones and moved through the audience, into the loudspeakers of an additional ambisonic sound-dome surrounding the audience (premiered at ZKM and IRCAM) and back into the audience's smartphones, while other layers of the work are only diffused through the smartphones. A film was made using 360VR footage and animations made from photographs of flowers and plant life in city parks, which further immersed the audience in the work.

Conceptually then, the performance of sound layers across the audience's smartphones transforms each individual from a passive listener into an active agent in the ecosystem of the work. *Future Perfect* sought to direct the audience's attention towards environmental ecology, stewardship and agency. It extends the audience's self into a communal space, sitting between the embodied experience of actively listening and the technology layer that creates the communal entanglement, a space Paine calls the Techno-somatic dimension (Paine 2015). It seeks to question the balance between what is considered 'real' or 'constructed'. Future Perfect drew on field recordings, images and virtual-reality footage captured in city parks. City parks are considered by most people as 'nature', but are conceived and built as part of the city's urban design. These urban parks and gardens were designed by somebody, maybe hundreds of years ago, but are constructed, artificially. *Future Perfect* plays with these

[2]http://cosima.ircam.fr. CoSiMa was supported by the French ANR National Research Agency (project ID <ANR-13-CORD-0010>).

[3]In our practices we generally rely on nano-computers that can run a fully fledged operating system and thus allow us to seamlessly reuse most of our software stack. However, such architecture can of course integrate microprocessors and specialised development boards by using more low-level network protocols such as TCP or UDP, and ad hoc dedicated software.

[4]More details can be found in the references.

[5]See www.activatedspace.com/Music/Future-Perfect/ (accessed 15 April 2021).

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dichotomies, immersing the audience in a journey where they are constantly moving from audiovisual environments that seem real into others that seem surreal and abstract.

In addition to the 360VR film and the ambisonic score, *Future Perfect* is performed from three web-based interfaces, run on separate iPads/tablets and utilises an ad hoc, closed, high-speed wireless network. The network name and password are made available to the audience on arrival. All the code for the clients and server applications runs from a single server on the performer's laptop, who can access and perform on all three complementary interfaces:

- The first interface is a spatialisation interface that allows for sound samples to be sent to the phones and then diffused across the audience. A trajectory can be drawn in real time by the performer or the radius of the sound sources can be controlled to generate expanding, spreading soundfields that grow or shrink within the audience. The server is performing vector-based amplitude panning across all the smartphones, adjusting the playback amplitude of the already playing and synchronised samples. New samples or collections of samples can be sent out across the network at any time with collections of samples being randomly distributed across the smartphones.
- The second interface allows the sample sound to be triggered for playback at any time, independently (per phone) or in groups, and allows for dynamic adjustment of loop points.
- The third and final interface controls a granular synthesis engine that also facilitates sending sounds to the phones played into a granular synthesis engine instance in the browser on the phone. This means that the granulation is associated with the sample and if collections of sounds are sent to the phones, different processing can be taking place on each phone. The granulator allows for a range of time-based manipulation that can create pointillistic, spatial effects through to shimmering textures.

All three of these compositional/performance tools run asynchronously and simultaneously opening up a huge pallet for real-time performance and composition options. It should be noted that any number of layers can be played asynchronously on the audience's smartphone/tablet. Each layer sent to the phone plays out its duration (i.e., if the sound is looping) but simultaneously, a new layer can be sent and activated on the phone. The phone's central processing unit capability is the only limitation to the momentary polyphony possible on the client's device.

3.2. 88 Fingers

From a completely reversed perspective, one of the more radical experiences we designed in terms of audience engagement and collective performance is a performance called *88 Fingers* during which 88 members of the audience each control a single key of a motorised piano (i.e., a Yamaha Disklavier) on stage using their smartphone (Schnell and Matuszewski 2017). The performance does not define any rules or limits, apart from the technical set-up and the duration of the concert (usually 10 minutes followed by a discussion and 10 more minutes of performance). Even if it is not generally possible to identify the individual notes played by the piano with individual audience members, the activity of the piano clearly represents 88 individual contributions by the movement of the piano keys and the associated sound of the notes. While – just as in many other experiences we designed – the individual contributions are limited and rather easy to perform, the challenge of the experience does not lie in the individual capacity of performing a single key but in the collective effort of mutual attention to each other's contribution.

3.3. Constella(c)tions

The *Constella(c)tions* project by composer Michelle Agnes Magalhaes (Magalhaes, Matuszewski and Bevilacqua 2020) proposes exploring another aspect of collective interactions: the movements and actions of the participants. The composer's artistic vision was to create musical compositions and scores as a series of collective 'games' whose rules implied texts, visuals and objects in spaces. Several pieces were composed as experiments between 2018 and 2020, with various configurations, from duets with professional performers to pieces including public participation.

The collective interaction takes advantage of the motion-sensing capabilities of the smartphones, all connected to a central server using a local network. The smartphone was either directly held by the persons or attached to objects such as long strings that could be 'played' by the participants. In this latter case, the smartphones were used as vibration sensors that translated the person's actions into sounds. Depending on the pieces and context, the smartphone speakers were also used, creating distributed sound sources. In other cases, the audio was rendered directly through standard speaker systems.

This series of pieces illustrates well the case where the designed and perceived collective interactions are not directly related to the technological network topology, which in all cases are built around a central server. The actions and movements are focused on

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the manipulation of objects between participants, helped in some cases by poetic instructions. Therefore, the audience's attention is directed towards the emergent network of perception and action, unaware of the technical network used to synchronise and mediate the interaction.

Extending these examples centred on the use of smartphones, another important aspect enabled by our framework and the recent spread of embedded hardware is the possibility to create networks of semi-autonomous musical agents. In recent years, such an approach has been explored by a variety of artists and composers including SquidSoup[6] and Oliver Bown et al. (Ferguson, Rowe, Bown, Birtles and Bennewith 2017).

3.4. Biotope

The first work using networked embedded hardware we want to present is the installation *Biotope* created by the composer Jean-Luc Hervé and created at the Centre Georges Pompidou, Paris in 2019. Described as a 'fearful acousmatic device' by the composer, the piece is created from approximately 30 nano-computers (Raspberry Pi), hidden in the walls of the exhibition space, that draw on a set of individual and collective rules to generate a song of simple and sparse, timid calls, through to complex polyphony. Following the model of living organisms, the agents of the system listen to and answer each other, and go silent or cry out when they perceive a human presence. Thereby, the interface between the network of agents and the human subjects is materialised through sensing distance, which creates within the network of agents a kind of perception of the physical world and allows them to react, both as individuals and as a group, to the presence of people in their surroundings. Here the interface between the network of agents and the public becomes a strategic actor in the creation of the relation between the two networks. Interestingly, this interaction is built upon passive and unintended actions from the human agents.

3.5. Poly

The second example, the installation *Poly* created by Benjamin Matuszewski (Matuszewski 2020a), takes a different approach. The installation is composed of five musical boxes, also built on top of Raspberry Pi nano-computers, spread out in the exhibition space that can excite cardboard resonators. The public can freely move the boxes from one resonator to another. Here the interface between the network of agents and the network of humans is provided by the physicality of the musical agent, which can be manipulated by the public (grabbing an object and moving it somewhere else). An important aspect here is that while the network of agents has no sensor to capture the interaction and does not react in any way to the manipulation, the simple physicality and the evolving geography of the installation is sufficient to get people to project and assign a certain agency to the sounding agents. Also, as the action of one single person modifies the space and, therefore, the perception of everyone, the mediation of the network of agents tends to reinforce the links between humans.

While these two last examples are far from exhausting the vast possibilities of interactions that can be created or described between a network of musical autonomous agents and a network of human beings made up from the public, they provide some insights on the way in which the networks can open interesting artistic avenues in terms of both design and analysis.

4. ON PARTICIPATION AND MUTUAL LISTENING

As is illustrated in the preceding examples, over the last decade we have experimented with interactive and participative approaches of sound installations and collective concert experiences in which the audience is actively involved in the production and induction of digital sound and imagery. In some experiences, participants interacted with digitally enhanced machinery or everyday objects, in others they just pulled their smartphones from their pockets to participate. These experiences ranged from concerts, where the sound of solo musicians had been rendered through the audience's smartphones, to collective improvisations where nobody but the audience collectively performed on web-based networked instruments. All these experiences had in common that – as is true with other interactive and participative works – they were designed with a particular attention to the actions of instrumented participants.

It may seem justified to argue that these experiences are particular because the audience here is more actively involved than in traditional concert performance practices of Western culture. One may claim that while traditionally the audience is 'just listening' without being involved in the production of the music itself, in participative works, the audience is 'really' and 'actually' involved in making the music.

However, after many years of creating experiences that merit their classification as 'interactive' and 'participative' due to their technical set-up, we have not succeeded in clearly distinguishing the previously mentioned 'active' participation of an audience from any other kind of participation. In general, the audience's participation in a musical experience is manifold and

[6] www.squidsoup.org (accessed 21 June 2021).

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hard to quantify, and this distinction does not seem to sufficiently describe the complex entanglements of the interactions involved – neither actually nor metaphorically.

The crucial difference, participation, introduces to the composition as well as the reception of the works a fresh and different perspective: it affords a significant shift of attention from strictly metaphorical or exemplary interactions musical works usually display towards actual interactions that involve the participating recipients.

Christopher Small, in the introduction of his book *Musicking: The Meanings of Performing and Listening*, argues that the 'meaning of the act' of making music lies in the relationship 'between the people who are taking part ... in the performance' (Small 1998). From this point of view, a different degree of activity in an audience's participation does not seem to make a notable difference. For instance, how do we justify the significant effort of instrumenting audiences (performing, listening, gesturing, being consciously part of an ensemble) as significant interactions beyond 'just listening'.

However, within the context of networked music-making, Small's argument helps us notice the different direction in which the listeners' attention is focused and the meaning therein. In the participative approaches, instead of listening to featured musical performers, the attention of the participants (the audience) is turned towards each other and to the collective they form. Each participant is listening to the others and this mutual attention is a critical distinguishable quality of these approaches and reflects the deeper meaning 'of the act' – actually and metaphorically.

Even in the case that not all members of the audience participate with the same skills or commitment, or where the participants may be assigned different roles in the performances, they are not participating in completely different categories, as would be the case for performers and the audience at a classical or rock concert, for example. Some of the experiences we designed featured performers who were clearly distinguished from the audience (e.g., on stage). In these experiences, the audience's contribution could be partly understood as dialoguing with the performer(s), partly as supporting their performance. Even if these two functions – or attitudes – may essentially be the same as for any other performance practices involving an audience, the experiences required and allowed for an enhanced mutual attention of all participants, individually as well as collectively.

An additional factor that enhances the perception of participation in many experiences we have designed is the distribution of sound within a physical space through a network of sound generators formed by the participants. The participants can usually clearly perceive the sound produced by their own device and the sound of individual participants around them while being immersed in the sound collectively produced by all participants together. The presentation of sound through tens or hundreds of devices produces a unique spatiality that the audience is immersed in and collectively represented by, namely, a soundfield that has remarkable depth and mass.

Ultimately, the perspective of participation also applies to works designed for interacting devices such as *Biotope* and *Poly* briefly introduced previously. Even if the works' interactions do not involve the recipients in the same way, they instantiate a very similar metaphoricity featuring the idea of mutual attention.

Involving either people or digital agents, or both, works that instantiate participation and mutual listening open new avenues of expression to composers and designers. While some may reject the idea that the musical outcome of each performance depends on the participants' interactions, others have embraced this idea as a desired factor of the overall creative process.

5. SUMMARY

Designs such as those discussed previously break down many of the traditional expectations of a musical concert presentation or art installation. The recipients actively participate in its realisation. In some works, this could be undertaken at any time of the day and in any place across the globe. The traditional, formal structures of presentation, curation and hierarchies of performer/artist and audience are therefore largely re-framed.

The ad hoc organisation whereby each individual becomes a formational agent also implies that anyone, regardless of existing skill or training, can become a musical agent, interacting with other musical agents in an act of mutual attention. Simultaneously, this individual experience is a communal one, forming a shared objective, and of course a shared experience of being both an individual creator and a community of actors and listeners.

It can therefore be argued that these changes of focus produce different experiences of artistic creation and performance, in forms of both presentation and engagement. The network then becomes the key medium that acts as an interaction platform supporting individual as well as collective expression and mutual attention. Interaction, here, is more than a set of metaphorical relationships displayed in sound on stage, as it is often the case in common musical practices, but it is actually instantiated through the recipients' own participation. Accordingly, the metaphoricities implied by such experiences are shifted

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from representations to embodied relationships acted out and mediated through the network.

Therefore, this type of work goes much further than replicating more traditional performances over networks, a format we saw greatly increasing in prevalence during the 2020–21 COVID-19 crisis. Artworks transmitted through network technologies, mainly used as 'communication channels', have often been reported as unsatisfactory in terms of collective experience, reproducing only very partially onsite interaction. The works presented here are fundamentally based on different approaches, considering the physical network as material in a complex and interleaved human(s) and object(s) interaction. Importantly, in the cases we considered, the collective interactions are designed as situated interactions, occurring in a shared physical space. As advocated here, these complex situations, superimposing social and technological interactions, objects and digital media, should be described and comprehended from a holistic perspective.

REFERENCES

Bischoff, J., Gold, R. and Horton, J. (1978). Music for an Interactive Network of Microcomputers. *Computer Music Journal* **2**(3): 24–9.

Deleuze, G. and Guattari, F. [1980] 2004. *A Thousand Plateaus*, trans. B. Massumi. London and New York: Continuum. (Originally published as *Mille Plateaux*, vol. 2 of Capitalisme et Schizophrenic. 1980. Paris: Les Editions de Minuit.)

Emmerson, S. (1994). 'Live' Versus 'Real-Time.' *Contemporary Music Review* **10**(2): 95–101. https://doi.org/10.1080/07494469400640331

Ferguson, S. J., Rowe, A., Bown, O., Birtles, L. and Bennewith, C. (2017). Sound Design for a System of 1000 Distributed Independent Audio-Visual Devices. *Proceedings of the Internation Conference on New Interfaces for Musical Expression*, Cogenhagen, Denmark, 245–50.

Gresham-Lancaster, S. (1998). The Aesthetics and History of the Hub: The Effects of Changing Technology on Network Computer Music. *Leonardo Music Journal* **8**: 39–44. https://doi.org/10.2307/1513398

Lambert, J. P., Robaszkiewicz, S. and Schnell, N. (2016). Synchronisation for distributed audio rendering over heterogeneous devices, in html5. *Proceedings of the 2nd Web Audio Conference WAC-2016*, Atlanta, USA.

Latour, B. (1996). On Actor-Network Theory: A Few Clarifications. *Soziale Welt* **47**(4): 369–81.

Leman, M. (2007). *Embodied Music Cognition and Mediation Technology*. Cambridge, MA: MIT Press.

Levin, G. (2001). Dialtones (a telesymphony). www.flong.com/storage/pdf/reports/dialtones_report.pdf (accessed 8 November 2021).

Magalhaes, M. A., Matuszewski, B. and Bevilacqua, F. (2020). STARTS Residency Public Report Constella(c)tions. https://vertigo.starts.eu/media/uploads/vertigo-constellactions-residency-public_report.pdf (accessed 8 November 2021).

Matuszewski, B. (2020a). [°poly°] – A Distributed and Interactive Sound Installation Based on Tangible Autonomous Agents. *Proceedings of the 27th IEEE Conference of the Open Innovations Association FRUCT*, Trento, Italy.

Matuszewski, B. (2020b). A Web-Based Framework for Distributed Music System Research and Creation. *Journal of the Audio Engineering Society* **68**(10): 717–26.

Matuszewski, B., Schnell, N. and Bevilacqua, F. (2019). Interaction Topologies in Mobile-Based Situated Networked Music Systems. *Wireless Communications and Mobile Computing*. https://doi.org/10.1155/2019/9142490

Paine, G. (2015). Interaction as Material: The Techno-Somatic Dimension. *Organised Sound* **20**(1), 82–9.

Robaszkiewicz, S. and Schnell, N. (2015). Soundworks – A Playground for Artists and Developers to Create Collaborative Mobile Web Performances. *Proceedings of the Web Audio Conference WAC-2015*, Paris, France.

Schnell, N. and Matuszewski, B. (2017). 88 Fingers. *Proceedings of Web Audio Conference, WAC-2017*, Queen Mary University of London.

Small, C. (1998). *Musicking: The Meanings of Performing and Listening*. Hanover, NH: Wesleyan University Press.

Turchet, L., Fischione, C., Essl, G., Keller, D. and Barthet, M. (2018). Internet of Musical Things: Vision and Challenges. *IEEE Access* **6**, 61994–62017. https://doi.org/10.1109/ACCESS.2018.2872625

Weinberg, G. (2005). Interconnected Musical Networks: Toward a Theoretical Framework. *Computer Music Journal* **29**(2): 23–39. https://doi.org/10.1162/0148926054094350

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