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Exploring the Motivations for Building New Digital Musical Instruments

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Abstract

Over the past four decades, the number, diversity and complexity of digital musical instruments (DMIs) has increased rapidly. There are very few constraints on DMI design as such systems can be easily reconfigured, offering near limitless flexibility for music-making. Given that new acoustic musical instruments have in many cases been created in response to the limitations of available technologies, what motivates the development of new DMIs? We conducted an interview study with ten designers of new DMIs, in order to explore 1) the motivations electronic musicians may have for wanting to build their own instruments; and 2) the extent to which these motivations relate to the context in which the artist works and performs (academic vs. club settings). We found that four categories of motivation were mentioned most often: M1: wanting to bring greater embodiment to the activity of performing and producing electronic music; M2: wanting to improve audience experiences of DMI performances; M3: wanting to develop new sounds, and M4: wanting to build responsive systems for improvisation. There were also some detectable trends in motivation according to the context in which the artists work and perform. Our results offer the first systematically gathered insights into the motivations for new DMI design. It appears that the challenges of controlling digital sound synthesis drive the development of new DMIs, rather than the shortcomings of any one particular design or existing technology.

Keywords

digital musical instruments; motivation; expressivity; embodiment

Exploring the Motivations for Building New Digital Musical Instruments

Over the past four decades, the number, diversity and complexity of digital musical instruments (DMIs) has increased rapidly. Defined here as devices for controlling digital sound synthesis (after Wessel, Wright & Schott, 2002), DMIs generate sound via a multi-step process that begins with some form of input from a human performer. This is typically an action or *gesture* (the latter is the standard term in DMI literature, e.g. Jensenius, 2014) that is executed on or with the instrument's control element (Fig. 1). The controller can take a diverse range of forms. Existing trends include the replication or augmentation of acoustic instrument interfaces (e.g. Gurevich & von Muehlen, 2001; Impett, 1994; Machover, 1992; Schiesser & Schacher, 2012) and the development of 'wearable' controllers that are directly attached to the body (e.g. Nakra, 2000; Waisvisz, 1985; see Miranda & Wanderley, 2006 for further examples). Input gestures are linked to their respective output parameters (i.e. particular sounds) via the mapping, the term that is used to describe the configuration of the relationship between the control and sound generation parts of the instrument (Hunt & Kirk, 2000; Hunt & Wanderley, 2002). The actual audio output is usually pre-coded in an audio programming environment on a laptop computer (e.g. Max/MSP, Csound, Pure Data, SuperCollider) and is triggered by the gestural input into the controller in the manner dictated by the mapping (Figure 1). - place Figure 1 about here - In contrast to most traditional acoustic instruments,[1] this form of sound production involves a separation of sound control and sound generation elements. This means that 1) DMIs do not have to be sources of sound in themselves, they can have any timbre or produce any sound regardless of the form or material of the control element; 2) no significant physical effort is required to create audio output from the instrument; and 3) DMIs can have any number of different input-output relationships, as determined by the mapping design. This possibility for endless

reconfiguration grants DMI designers and performers a very high degree of flexibility for music-making.

Organologists have identified a range of possible motivations for the creation of new musical instruments, including economic, social and political factors alongside creative and artistic motivations (Bijsterveld & Peters, 2010; Libin, 2000). However, by and large, the limitations of particular technologies have historically inspired the development of new instruments or modifications to existing ones. Examples include limitations in pitch or dynamic range (e.g. the restricted dynamic range of the harpsichord encouraging the development of the modern pianoforte, Bijsterveld & Schulp, 2004), limitations in the ease of use from the performer's perspective or in terms of manufacturing which was, for instance, partly responsible for the success of the upright piano over square models (Libin, 2000, p. 199). Given that there are few limitations on DMI design, what motivates the development of new DMIs in artistic settings?[2] Despite the prevalence of such devices in both academic music departments and in dance music/club settings, there is little to no systematic research on this topic. We investigated the possible motivations for producing new DMIs via an interview study with ten artists active in the field of DMI design.

The existing scholarship in this area is largely restricted to published accounts by instrument designers detailing the decisions involved in the design process of a particular DMI. This body of self-reflective 'artistic research' (cf. Borgdorff, 2010 for more on this term) along with the small number of theoretical works on DMI development (e.g. Kim, 2012; Miranda & Wanderley, 2006; Théberge, 1997) provides some background information from which it is possible to infer three potential motivations for the development of new DMIs.

The first of these possible motivations is that of improving physical control over digital sound synthesis or aiming for a more *embodied* experience when performing electronic music. The production of sound through digital sound synthesis does not require any significant physical effort and therefore, electronic musicians seek to create devices that

build in a more intuitive means of physically controlling sound parameters, expressing dissatisfaction with 'laptop-based' setups (e.g. Bennett, Ward, O'Modhrain & Rebelo, 2007; Graham & Bridges, 2015; Magnusson and Mendieta, 2007; van Troyer, 2014). Morreale, McPherson & Wanderley (2018)'s survey of DMI performers identified several artists that choose to perform with instruments that gave them a more satisfying sense of control. The idea of increasing the level of 'embodiment' or of striving for a more 'embodied' approach to music-making frequently occurs in this context (Kim, 2012; Leman, 2008). It commonly refers to a desired transfer of physical energy into a sound-producing device, usually achieved by incorporating more nuanced, continuous forms of control. This is, for example, the central point of Miranda and Wanderley's monograph (2006) on DMIs, which provides a summary of the trends in new interface design that go beyond the more established discrete control paradigms of the keyboard setup and the buttons, knobs and sliders on industry-produced MIDI controllers.

A second possible motivation may be to place an emphasis on the audience's experience of a performance and design new DMIs that make the live performance of electronic music enjoyable and interesting to watch. A number of studies point to the difficulties in comprehension audiences face at DMI performances (Barbosa, Calegario, Teichrieb, Ramalho & McGlynn, 2012; Berthaut, Coyle, Moore & Limerick, 2015; Bown, Bell & Parkinson, 2014; Emerson & Egermann, 2017; Emerson & Egermann 2018; Gurevich & Fyans, 2011; Marquez-Borbon, Gurevich, Fyans & Stapleton, 2011) and proposals have been made for systems that provide more information on the workings of the instrument during performance. Berthaut, Marshall, Subramanian and Hachet (2013) designed a display system that can be placed under a tabletop DMI and illustrates the ongoing sound generation process via 3D visualisations. There are also several live coding performers who include projections of their screen display in their setup, allowing spectators to see how changes in the code affect the sounds generated (Brown & Sorensen, 2007; Brown & Sorensen, 2009; McLean, Griffiths & Collins, 2010). There have been calls for instrument designers to

actively consider the audience's perspective in the design process (Croft, 2007; O'Modhrain, 2011), which could inspire and motivate the creation of new DMIs that engage audiences more directly.

A third and final potential motivation that arises from existing literature is that of wanting to produce new sounds or timbres with which to make music. This wish to work with new timbres drove the development of some modern acoustic instruments (e.g. the hang, invented in 2000, Rohner & Schärer, 2007). It was furthermore the principal motivation of many of the early pioneers of noise and electronic music, such as Luigi Russolo and Edgar Varèse. Russolo, in his Futurist music manifesto, *The Art of Noises* declared that it was necessary to "substitute for the limited variety of timbres that the orchestra possesses today the infinite variety of timbres in noises, reproduced with appropriate mechanisms" (1914/1986, p. 28). Varèse went as far to envisage that, via the introduction of new electronic instruments, timbre as a parameter of sound would take on a foreground role in the composition process and no longer be "incidental, anecdotal, sensual or picturesque" but rather "an agent of delineation like the different colours on a map separating different areas" (Varèse & Wen-chung, 1966, p.12). The desire to generate new timbres may well drive DMI development, but since such instruments largely have no finite sense of timbre, this is perhaps less likely to be the case. Rather, developing new means of controlling and manipulating timbre could be a more likely motivation.

Aims and Study Design

Responding to the lack of empirical research specifically on this topic, we aim to investigate the motivations experimental electronic musicians may have for wanting to build their own instruments. We found qualitative interviews to be an appropriate research method for this investigation, as it allows for the explorative collection of detailed information on individuals' motivations and has been previously used in research on motivation, creativity

and artistic practice in music (Barrett, 2006; Bijsterveld & Schulp, 2004; Blom, Bennett & Wright, 2011; Kennedy, 1999).

As the existing literature on DMI design does offer some potential motivations for new instrument design, we chose a deductive approach to category construction (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005: 1281; Mayring, 2000; Schilling, 2006). This method involves the testing of categories that arise out of existing research, whilst also allowing for the emergence and inclusion of new categories during analysis. We therefore approached our interview study with three proposed categories of motivation:

M1: Wanting a more embodied experience when performing and producing electronic music

M2: Wanting to make the activity of performing electronic music more interesting to audiences.

M3: Wanting to develop new sounds or timbres.

A second research question following on from this primary investigation considered the extent to which these motivations might relate to the context in which the artist works and typically performs in. This secondary aim was realised in a purely explorative manner.

Method

Participants

We conducted semi-structured interviews with ten artists (all male), who are prominent performers in the field of experimental electronic music and build their own DMIs (see Table 1). The ten participants, except for RH, all had an existing connection to the 3DMIN research project (e.g. had given a visiting lecture as part of the project event series or had an institutional connection to the project), which facilitated the organisation of interviews. Attention was paid to gathering a range of developers at different stages in their careers, in

order to ensure a broad, varied sample for the interview study, and from both academic and club music contexts to explore the relationship between context and motivation. Table 1 provides basic information on the interviewees and their new instruments. MR is a collective of three individuals who design instruments and perform together. As they make creative decisions jointly, we treat them here as one artist.

-place Table 1 about here-

Data Collection and Analysis

The interviews were structured into six blocks of questions (see Appendix for Interview Protocol): 1) background information (e.g. education, present day activities, basic motivations); 2) questions about the development of the instrument(s) (artistic intentions/vision, production costs, open source components); 3) questions about the technical specifications of the instrument and its sound production; 4) questions about the procedure of a typical concert; 5) questions about how the interviewee's setup/performance style might differ from that of other artists; and 6) questions about the performer's use of their body and physical energy in relation to their instrument (e.g. importance of haptic feedback from the instrument, awareness of any embodied music production/cognition theories). As far as possible, the interview structure was kept the same for each interview. The interviewees were encouraged to answer the questions freely with as little follow-up from the interviewer as possible. The interviews took place at various locations in Berlin, were conducted in either English or German[3] and were recorded with a Zoom H-1 audio recorder. They ranged from 37 to 100 minutes in length and all took place in within a timespan of 11 months.

We conducted a deductive content analysis of the transcribed interviews. The three proposed categories of motivation (M1: Greater Embodiment in Performance, M2: Improving Audience Experience, M3: Developing New Sounds) were added as codes into

Atlas.ti (Version 1.0.48). The transcripts were then read through multiple times and quotations relating to the proposed themes were annotated accordingly. The first author repeated this initial coding three times so as to ensure that any new codes that emerged during the analysis could be applied to all interviews. The second author then reviewed the coded transcripts and agreements on interpretation were reached between the two authors. The first author found 51 motivations and four categories. The second author agreed with these 51 codings and then found a further 10 possible motivation quotations on review. After an extensive discussion, we agreed on 57 quotations across four categories. There remained one uncategorisable quotation from TA (see discussion on Page 16).

While Atlas.ti was primarily used as a tool for organising and annotating during the coding process, we also used the software to produce a summative analysis of the coded quotations (Hsieh & Shannon, 2005). This involved calculating totals of quotations for each category in order to assess the relative importance of the categories (reported in Table 2 below).

Results

Motivation Categories: 'Humanising' Computer Music (M1 and M2) vs. Using Technology for Artistic Exploration (M3 and M4)

In total, the interviewees mentioned their motivations for building DMIs on 57 occasions. Almost all of these 57 quotations could be sorted into the three proposed motivation categories, thus confirming our expectations regarding possible motivations. Out of these three categories, the motivation of wanting a more embodied experience when performing and producing electronic music (M1) was the most frequently cited. While our interview protocol (see Appendix) did feature a more direct question on embodiment (in Block 6), all interviewees except HT had already mentioned being motivated by the desire for a more embodied control over digital sound synthesis prior to this final set of questions. It therefore does not appear that these interview questions biased our results.

Over the course of the analysis, a fourth category emerged: the motivation of using technology (in most cases, machine learning algorithms) to create instruments or systems that introduce elements of uncertainty into a musical performance and can therefore act as responsive partners in improvisation (M4). This intention may seem contradictory as it involves a loss of performer control but it is relatively common, especially among DMI artists who perform improvised music (e.g. Lewis 2000; Linson, Lewis, Dobbyn & Laney, 2015). Another related approach is simply to incorporate randomisation features, such as a SuperCollider patch for randomising the instrument's mapping design (e.g., de Campo, 2014).

-place Table 2 about here-

On the basis of this initial analysis, we decided to group the four categories under two larger themes or intentions. The two most frequently mentioned motivation categories, M1 and M2, can be viewed as originating from the more general intention of increasing human involvement, presence and physicality in the production of electronic music. Quotations for these two categories frequently identified an explicit problem that the artists felt motivated to rectify through instrument development, either the lack of expressivity or enjoyability when playing existing (typically laptop-based) systems from the performer's perspective (M1) or the lack of emotional connection between computer music performers and their audiences (M2):

Quotations from M1 (Greater Embodiment in Performance):

> I wanted to improve the mechanical link between computer music and people, because I thought we should have a better way of interacting with these kind of systems so that it's more personal or more intimate or more enjoyable. (EB)

So I like to have coherence between what I am hearing and what I am doing with my body. So that's important for me. To be able to do these big gestures that follow the music and having this strong controller I can be harsh with. (MR)

Another reason is that if you're sitting, most of your body is not involved in the actual gesture of making the sound. So an instrument is a device that requires an interface to the human body. You have to do some kind of physical action on the instrument that can make sound [...] because if you press a button that says 'start' or 'loop' or something it's a machine, it's not an instrument. (RT)

For me, it's really that I have to like the instruments I'm playing with. It's not enough for them to allow me to do what I want because of their technical specifications, I need to build a personal relationship to them. It has to be enjoyable for me to play with [...]. (RH)

[...] you know my performance is very, very physical compared to other electronic musicians. [...] But I have this intensity of physicality and I think not so many electronic musicians are working in this field. I'd like to see such kinds of performance. (TA)

Quotations from M2 (Improving Audience Experience):

My main influence when building the instrument was the irritation that I had from attending electronic music concerts with live performers. I found that the lack of nuance in the control paradigms was literally in the way of the music. I found the relationship between input controllers and sound to be banal. (BH)

I like to use more direct mappings which I think in my opinion is more challenging, but I hypothesise that the audience is more interested in the result if they can understand

what's going on. Because otherwise if you're just seeing someone perform something and you can't understand at all how they're controlling the sound, how do you know they didn't just hit play on the CD player and then they're just pretending to perform? You can't tell the difference. (EB)

What degree of connectedness can you achieve if you're sitting at a table and either turning knobs or clicking on a laptop? [...] So the reason that I prefer portable instruments is because I can play standing. I can just stand in front of the people. And I think the sense of being together and sharing the space between the musician and the audience is much more... is like.. it's closer.. (RT)

But what I see in the majority of cases is this typical situation of sitting, very often with a computer and I believe that there's a general feeling of insufficiency. Something is lacking, something is not fully satisfying. And I think both the audience and the artist feel that. (RT)

The sense of motivation encompassed in categories M1 and M2 appears to be driven by the will to solve the larger problems that arise out of the use of digital technologies in music production. In contrast, quotations from the categories M3 and M4 mention the motivation of using technological means to achieve the artistic aims of developing new sounds or building a system to improvise with:

Quotations from M3 (Developing New Sounds):

If you think back to how computer music began, people with musical ideas had access to computers for the first time and wanted to discover what kind of new sounds can they make with computers that are not feasible to make using analogue technology. So what I'm working on is discovering what kind of new sounds or what kind of new musical

interactions we can have using a force feedback device that were not possible before. (EB)

But when it comes to my thinking, I am totally interested if there is a sonically interesting timbre, sound, and then I am all there. So I think whatever I am doing [...] it will have some sonically interesting outlook. (HT)

Quotations from M4 (Building Responsive Systems for Improvisation):

I am the kind of improviser who needs to be surprised, who needs to be like on the edge of the seat, see what's happening, that could be the sound in the room, how does the room react to what you are playing, if I play with other people, other people bring the surprises to me. But I figured when I do solo performances, the best is if the computer surprises me. (HT)

And so one thing that I have experimented with is simply randomly changing the processing every single time you play a note, it's just always something different. And that's kind of fun, it's very destabilising and very interesting to do. (MP)

I'm always searching for the borderline between the aspects I can control and I cannot control. I think in that point [my instruments are] totally different from any kind of traditional instrument. (TA)

We identified two larger trends in motivations for instrument building that are each comprised of two smaller categories. Naturally, these smaller categories were not always so easy to separate during analysis; a number of single comments could be interpreted as referring to multiple motivations. For example, MR, a collective formed of a duo of computer musicians plus an audiovisual design specialist, seemed at times to have a

combined motivation of wanting greater embodiment in performance and of wanting to improve audience experience, in which the instrument mediates between them and their spectators:

> No, [the instrument] is a mediator also. Because we want people to know that they are made of cardboard and that we can destroy it. Sometimes on stage I destroy my instrument at the end of the performance and that's of course a way to excite people. (MR)

> Once at the end I threw the instrument away into the audience and they were fighting to see who would get it. So, of course you can not get more in touch with the audience with an instrument than give it to them. (MR)

Here, the same feature of the instrument that allows for greater portability and physicality, namely that it is made of cardboard (see MR quotation above), enables the artist to provoke the audience through its temporary nature. Category M1 in itself furthermore covers a wide range of interpretations of what exactly increasing embodiment in DMI performance means. While some interviewees mentioned specific methods of increasing haptic feedback from the instrument (e.g. EB and ML) or modelling the playing technique on that of an acoustic instrument (e.g. MP), for RH, part of this more embodied experience involved having a more nuanced control over the instrument and needing practise on it in order to master this finer-grained control:

> This criterion is also applicable here, that [the instrument] is not designed to be universally usable and that it offers a very personal, very specific range of possibilities. And within these possibilities, it offers both very fine-grained but also radical modes of interaction in real-time and thereby fulfils all criteria of an instrument for me. Namely that I have to

> practise, I can improve it through skill [...], I have to learn, I can learn it, and when I've learnt it, I become better. (RH)

Aside from the 57 motivation quotations categorised as above, there remained one quotation from TA which defied clear categorisation:

> And if I played a [conventional] instrument, I noticed people compared me to other instrumentalists. So if I played the piano, there are so many pianists. So people tend to compare and basically talk about technique. And I think that is a very boring thing. Of course my approach was already different, but I felt I couldn't avoid such kind of competition if I played a conventional instrument. And then I thought: I'll build my instrument. (TA)

This seems to hint at a possible fifth category, a social motivation of not wanting to be compared with other instrumentalists and seeking to avoid competition through developing one's own instrument. Designing and performing with DMIs can represent a way of creating new performance and concert setups, ones that are free of the baggage that comes with traditional instruments (cf. collaborative instruments such as the reacTable, Kaltenbrunner, Jorda, Geiger & Alonso, 2006; or experiments in outdoor music-making, Greie-Ripatti & Bovermann, 2017; see also Magnusson and Mendieta, 2007, p. 97 for a discussion on the issue of performance traditions and instrument development). However, as no other participants mentioned a similar motivation and TA did not elaborate on this, we did not see grounds for developing it into a category.

Motivation and Context

In a subsequent analysis, we explored the relationship between the motivation to develop a new DMI and the context in which the artist works and performs. The interviewees were sorted into three context categories (C1: Academic, C2: Club, C3: Mixed (Academic and Club) based on how they described their present activities and the settings they perform their music in. EB, MP, BH, and HT all hold positions at universities and teach classes in electronic music and instrument design. TA does not hold a formal position but gives lectures in academic settings. MO, MR and RT all referred to playing in a mixture of settings, including electronic dance music venues and university-based workshops and conferences. ML and RH perform only in club contexts.

- place Table 3 about here –

As can be seen in Table 3, there appears to be a strong relationship between the participants' performance contexts and their motivation to build DMIs. Those artists working in the club scene have a much narrower range of motivations than those situated in the academic context; their interests are more focused around achieving greater embodiment in performance (M1) and improving audience experience (M2). RH, for example, develops setups which allow him to perform from directly within the crowd of audience members:

> For me, the result is that I bring myself into the position of the audience. Literally, physically. I play in the middle of the audience and then I don't need any monitors or any form of translation between myself and what the audience hears, I know entirely, that what I'm hearing is what the others are hearing. (RH)

It is logical that a club performer would focus on establishing a relationship with the audience, given that those attending a performance in a club setting are there to dance and socialise, not simply to listen. RT, who also often performs in club settings, although not

exclusively, places a similar emphasis on wanting to improve the audience's experience, citing the visible presence of the performer as an important element in this:

> It's an interesting question, because I've always believed that live music is something to be heard but also seen and I always had this strong conviction that if you're on a stage you have to be seen. That's the reason why you are there because people want to see you doing your stuff in front of them, that's the reason for the live situation. (RT)

Out of the artists in the context categories C2 and C3, it is only ML who is not motivated at all by the intention of creating a particular experience for the audience. In fact, he places little importance on the visual aspects of his performances and appears to be uninterested in the audience's perspective and their level of understanding:

> With my setup, you don't really see anything at all. [...] And somehow, the visual aspect is just not very important to me, to be honest. The sounded result has to be right. (ML)

> *How important is it for you that people understand what you're doing?*
> I can't really say that that's very important to me. And I think, well, I have the impression sometimes that most people do not actually understand. But that's not very important to me. I know what I'm doing. (ML)

It is unclear why the two exclusively club-based artists, RH and ML, were not motivated by the desire to develop new sounds. It is possible that club musicians simply seek to set a particular atmosphere or just to entertain through their output, rather than push at musical frontiers, but this is not a satisfactory conclusion. Certainly, as freelance club artists, they are more reliant on the positive reception of their music by audiences than academic artists are. RH and ML do both improvise in their live performances but, despite this, do not appear

to be motivated by M4. This is perhaps because a different type of improvisation is favoured in club settings, one that does not require such active feedback from the system.

The broader range of motivations in the academic setting (C1) can most likely be attributed to the higher level of self-reflection that is common in this context. DMI artists who are active in academic research are often familiar with the literature surrounding electronic music practice and are also sometimes engaged directly in artistic research, a practice that promotes a reflective, documented approach to creative work (Blom, Bennett & Wright, 2011). It was generally the case that their answers to the interview questions were more detailed. For example, EB, who holds an academic position, made references to literature on DMI design when talking about whether to define his DMI as an 'instrument' or a 'controller':

> *So the Firefader is a controller.*
>
> So the Firefader is a controller actually, I mean in a rigorous sense. You asked me to mention three instruments, so I mentioned it. But it's true, it's not really specific until you're using a specific sound synthesizer and a specific mapping also. I think if you look into the book written by Wanderley and Miranda, you'll probably find a similar definition. (EB)

It is also notable that M4, the motivation of building responsive systems for improvisation, is found almost exclusively in the academic setting. This is perhaps because DMI artists in academic contexts are more likely to be involved in pushing the technological advancement of this branch of music technology. Most DMI systems that involve artificial intelligence of some kind have been developed in academic contexts, probably due to the more reliable funding structures in place in this context (see Blackwell & Young, 2004; Borgo 2005; Linson, Dobbyn & Laney, 2012; Marley & Ward, 2015; Miranda & Wanderley, 2006). Designers in the academic context, such as RT, gave detailed explanations on the

merits of losing control and being surprised by the DMI system, voicing frustrations with setups that centre around fixed, discrete elements (e.g. the keyboard setup):

> And that's a privilege of electronic music, because it can be really built in, how the instrument is designed to have this degree of randomness [...] I find it very exciting to work with instruments that are responsive in the very split second to any performing decision, but then what they give you is something that is approximate to your intention. So you want to make a sound and you know the sound is going to be, going to have this characteristic and it does, but it's not quite what you imagined. (RT)

While motivations for DMI production are in many instances very individual, it does appear possible to classify the motivations artists have according to the context they work in.

Discussion

The participants in our study reported being most motivated in their production of new DMIs by the desire for a more embodied experience when performing and producing electronic music (M1). Just under half of all the references to motivation mentioned this and only one participant, BH, did not report this at all. This aim, along with the second most frequently cited category, M2 (improving audience experience), suggests that developers of new DMIs are motivated by the need to turn digital musical technologies into musical instruments and to produce performative tools that function successfully within individual and social musical contexts. Their work is driven primarily by the broader need to humanise music-making with new DMIs (75% of quotations) and only secondarily by more individual artistic and musical goals (25% of quotations). The prominence of this theme in our interview data mirrors the prevalence of discussions on embodiment and expressivity in the DMI literature (Arfib, Couturier & Kessous, 2005; Jensenius, 2014; Jordá, 2004). It could also suggest that musicians in this field have yet to fully harness the potential of digital

technologies for music-making; there is still an over-focus on the means of musical production, rather than the ends.

M3, being motivated by the search for new timbres, only accounted for 14% of quotations about motivation.The creation of specific new sounds may have become less important in electronic musical instrument design since the advent of digital sound synthesis, as it essentially provides the means for the production of any imaginable timbre (Jordá, 2004). Magnusson (2010) speaks of a 'creative paralysis' in the face of the limitless possibilities presented by current audio programming environments, a development the early pioneers of electronic music referenced above probably did not foresee. While a sense of 'paralysis' around sound design was not expressed by any of our participants, it may be the case that the need to search for new sounds has been satiated by the timbral freedom digital sound synthesis offers, and thus M3 was not more frequently mentioned in our study.

While our expectations about the possible motivations for new DMI design were confirmed (M1, M2 and M3 were able to explain most of the data), an unexpected category, M4, emerged during analysis. The motivation to build responsive systems for improvisation that can surprise and challenge the performer certainly contrasts the motivations behind the development of most existing acoustic, electronic and digital instruments, for which the optimisation of performer control and the reduction of randomness or uncontrollability has been the focus. Using machine learning methods to introduce the 'right amount' of randomness and develop systems that can be partners in musical improvisation marks a step in a very interesting direction for the future of music-making.

There were some detectable trends in motivation according to the context in which the artists work and perform. Those working in the club (C2) and mixed contexts (C3) were more interested in humanising computer music production, whereas the artists from the academic setting displayed a broader set of motivations, more often encompassing the achievement of artistic or musical aims. It is, of course, difficult to say whether context and motivation influence each other in any way; motivation could relate to which context artists

end up working in but it is more likely the case that this choice of context comes about through a range of different factors, including academic background, available opportunities at the individual's time of study and even socioeconomic factors. Once someone becomes associated with a particular context, it is also possible that their motivations to produce new DMIs change to adapt with the surrounding environment. Those working in the academic context, for example, may well be required through teaching and research commitments to become familiar with the theoretical literature on DMIs or to focus on developing specific branches of music technology (e.g. computational creativity), which could in turn alter their motivations and how they reflect on them.

Our investigation lays the groundwork for the development of future hypotheses regarding possible DMI design motivations and how these come to be formed. In order to test the broad trends we have found here, our study would benefit from being replicated with a larger sample size and with more musicians exclusively active in the club scene. There is also a number of related questions that could be addressed in a follow-up study. A comparative interview study with designers of acoustic instruments would allow for the confirmation or rejection of some of the differences between these two worlds of musical instrument design that we propose here. It would also be illuminating to include perspectives from DMI designers working in industry, who could potentially have a different set of motivations from those working in club and academic contexts.

Our results offer the first systematically gathered insights into the motivations for new digital musical instrument design. It appears that it is the limitations or challenges of controlling digital sound synthesis itself that drive the development of new DMIs, rather than the shortcomings of any one particular instrument design. It is also evident that DMI production involves a complex array of concepts and issues, including control, embodiment, expressivity, virtuosity and musicality. These terms are each interpreted differently by individual designers and performers, making for a diverse and ever-changing branch of musical practice.

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Tables

Table 1. List of Participants, their Professional Backgrounds and their DMIs

Participant ID	Years Active	Professional Background	DMI
BH	21-30	Flute performance	Augmented Flute
EB	10-20	Engineering, Music technology	Force-feedback device, Haptic Drum
HT	40+	Guitar performance	Augmented Guitar
ML	31-40	Sound engineering, some classical piano experience	Sequencer + Buchla 200e[1]
MO	31-40	History, postgraduate electronic music studies	Wearable Glove Controller
MP	31-40	Mathematics, guitar performance (no formal training)	Augmented Guitar plus filter/pedal system
MR	10-20 (playing as collective for 8 years)	Mathematics, architecture, composition	DIY-Controller (cardboard box with buttons and joystick control)
RH	21-30	Sound engineering	MIDI controller (Sequencer/Mixer)
RT	31-40	Guitar performance (no formal training)	Toy Instruments, Portable Amps and Augmented Guitar
TA	21-30	Philosophy, some classical music experience (flute, piano, percussion)	Wearable Sensor Controller

Table 2. Number of Quotations per Motivation Category for Each Interviewee (Summative Content Analysis)

	'Humanising' Computer Music Production (75% of Quotations)		**Using Technology to Realise an Artistic Aim (25% of Quotations)**	
Participant ID	**M1: Greater Embodiment in Performance**	**M2: Improving Audience Experience**	**M3: Developing New Sounds**	**M4: Building Responsive Systems for Improvisation**
BH		2	1	
EB	4	3	2	
HT	1		3	2
ML	3			
MO	1	1	1	
MP	3	1	1	1
MR	6	3		
RH	7	1		
RT	1	4		1
TA	2			2
Total Quotations Concerning Motivation: 57	= 28 (49%)	= 15 (26%)	= 8 (14%)	= 6 (11%)

Table 3. Motivation Categories cross-classified by Interviewee Work/Performance Context

	C1: Academic	**C2: Club**	**C3: Mixed (Academic and Club)**
M1: Greater Embodiment in Performance	EB, HT, MP, TA	ML, RH	MO, MR, RT
M2: Improve Audience Experience	BH, EB, MP	RH	MO, MR, RT
M3: Create New Sounds/Timbres	BH, EB, HT, MP		MO
M4: Build Responsive Systems for Improvisation	HT, MP, TA		RT

Figure

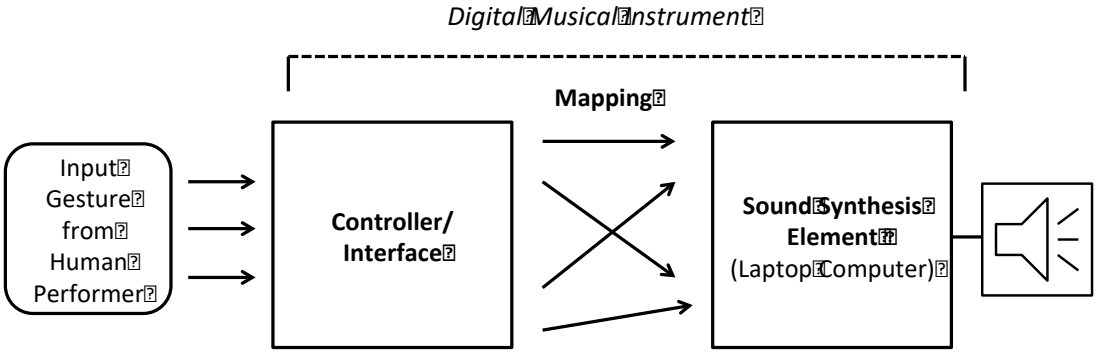

Figure 1. The process of sound generation with a Digital Musical Instrument.

Appendix: Interview Protocol

1) Please tell us about your background and your interests in music and technology.

Points for follow-up questions:
- personal information
- technical or artistic education
- present day activities
- motivation

2) Please tell us about the development of your instrument(s).

Points for follow-up questions:
- idea/vision
- links to theory
- costs/amount of time
- open source aspects?
- completed or continuous development?

3) How do your instrument(s) work?

Points for follow-up questions:
- sound production/synthesis
- direct access to musical parameters
- mapping
- spatialisation

4) Please give us a report about the procedure of your last concert.
(no specific points for follow-up questions)

5) You probably often have the opportunity to watch other artists perform and to observe their interactions with their instruments. What do they do during their performances?

Points for follow-up questions:
- contrasts to your performances?
- extroverted or introverted performance style?
- is the performance understandable/readable?
- overall audiovisual experience

6) How do you use your body during a performance/when interacting with your instrument(s)?

Points for follow-up questions:
- gestural control
- does the instrument give resistance or feedback?
- any concept of energy transfer between performer and instrument?
- do you see the instrument as a mediator between you and the audience?
- any link to theories of embodied music production or cognition?

Notes

[1] See De Souza (2017, pp. 38-45) for examples of separate sound control and sound generation elements in acoustic instruments.

[2] DMIs have also been developed for use in pedagogical and therapeutic contexts, our focus here is however only on DMIs used for artistic creation.

[3] RH and ML were interviewed in German. The quotations presented here were translated into English by the authors.