# Insights Into How Digital Luthiers Approach Design

Nathan Renney
Expressive Computer Interactions
Univesity of West of England
Bristol, UK
nathan.renney@uwe.ac.uk

Benedict R. Gaster
Expressive Computer Interactions
Univesity of West of England
Bristol, UK
benedict.gaster@uwe.ac.uk

## ABSTRACT

The design of digital musical instruments represents a complex role that incorporates creative practice, design and engineering. It is, of course, a deep discussion topic and research focus within the NIME community. This paper discusses how digital luthiers approach design through a reflexive thematic analysis that inductively explores their practice. This work builds on a study that includes interviews with 27 digital luthiers from various backgrounds and varied motivations, originally motivated to better understand tool use in digital lutherie. The themes presented provide constructed narratives that affirm assumptions that intuitively appear likely and provide interesting insights and developments for further exploration that are fitting and relevant to the NIME community. This discussion finds nuances in how digital luthiers approach design as a problem and in search of inspiration. It also explores how interaction and control are often the primary focus of digital luthiers and that they emphasise opinionated and directed design choices. These ideas are then considered in relation to existing ideas from the field.

## Author Keywords

NIME, Design,DMI, Digital Lutherie, Thematic Analysis

## CCS Concepts

**•Applied computing → Sound and music computing; •Human-centered computing → HCI theory, concepts and models;**

## 1. INTRODUCTION

Much like the term digital musical instrument (DMI), digital lutherie is used to refer to a fluid and interpretable concept. Though the term digital musical instrument is a common term used in music technology research, the term does not have a broadly accepted definition. Miranda and Wanderley [28] suggest that a DMI is an instrument that uses 'computer-generated sound' and features a control surface to act on musical parameters in real time.



*NIME'24,* 4–6 September, Utrecht, The Netherlands.

The interviews from this study suggest it is difficult to be prescriptive in defining DMI. In this work, participants suggest DMIs may require some adherence to the use of discrete systems or real-time performance capacity. But ultimately, it is clear that exceptions are abundant, and providing a concrete definition of the term actually has very little function in the wider sense of instrument creation. Much like DMIs, Digital Lutherie is a term used to capture a wide range of practices in the multifaceted role of designing and using DMI, often incorporating the designer, builder and performer in various permutations [23]. Such a role captures many different backgrounds and approaches to design and likely offers nuanced ideas valuable in both digital lutherie and the wider context of design research.

This paper is based upon a previous study and analysis [32], presenting an additional reflexive thematic analysis of 27 standardised open-ended interviews with prominent digital luthiers to provide an introspective exploration of their ideas. Using an inductive approach to analysis, four themes are generated titled 'Problem Solvers', 'Inspiration Seekers', 'Opinionated Designers' and 'Interaction and Mapping'. These themes provide both an affirming reflection of the concepts pursued in the field of DMI design and suggest details and complexities that may feed into future investigation and discourse.

## 2. BACKGROUND

The practice of design is predominantly researched within domain-specific contexts as generalisations of design have failed to effectively incorporate aspects such as the creative and innovative requirements of design [36, 35, 9]. C-K theory was presented in an effort to better reconcile these requirements, but despite the attempts to incorporate these factors [20], the research design community has not settled upon it. It is suggested by Dorst [14] that design research exists as a dynamic interaction between fields and suggests that discussion is enriched by the cross-pollination of different fields. Digital Lutherie naturally connects fields such as software engineering and craft practices to create a highly interconnected design space that incorporates many domains [21]. Goel and Pirolli [19] suggest that the knowledge required for a solution in design draws on a near-limitless set of domains, forming a 'design problem-space' in which the designer operates. Ideas such as digital craftsmanship explore the role of digital lutherie through the lens of craft practice [2, 3, 4], drawing constructively on ideas from programming languages [7, 18] and e-textiles [30] to identify the digital mediums used as the materials that the digital luthier works with. We can even look to the variety in NIME publications itself to see that these ideas draw on varied domains to explore the landscape of DMIs, and the focus of deepening the understanding of digital

**Figure 1: Reactable, Gechologic Loopsynth, EMG Instrument, The Blade Axe, Ableton Push, Bastl Kastle Drum**

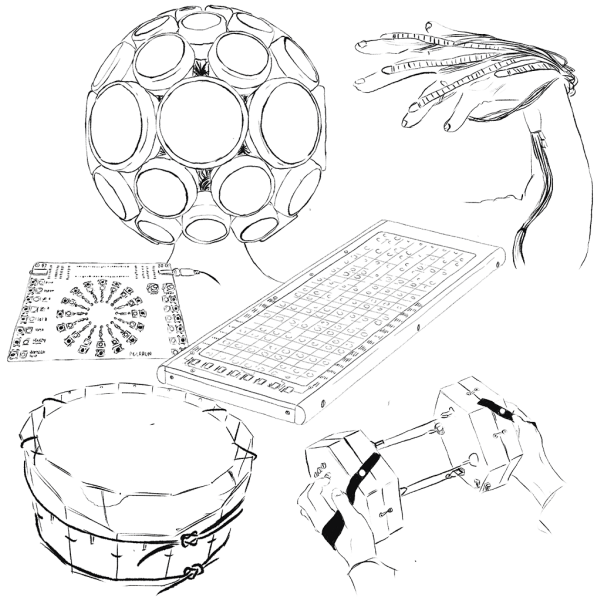

**Figure 2: Alpha Sphere, Ladies Glove, Polaron, Linnstrument, The Daïs, Concertronica**

lutherie is only growing as it becomes more apparent that the performance and creation of DMI are often intrinsically linked [23, 2]. As previous work based on the study presented in this paper indicates, digital lutherie is a flourishing example of end-user development in practice [16], showcasing meta-design [17] and social creativity [15] throughout the DMI design ecosystem. Mirroring DIY and maker culture [37], digital lutherie continues to lower barriers to access and democratise the high-performance technology required for digital lutherie [29, 27, 25, 38], constructing a new archetype of designer who is no longer a specialist in one area but stradles many domains.

# 3. METHODOLOGY

## 3.1 Motivations

This study was originally designed to investigate how digital luthiers choose their tools, particularly in relation to the programming languages they use. The authors provide personal statements to contextualise their background and motivations as researchers in a prepublication [33], published ahead of the study this work is based upon. Due to the rich nature of the data produced through this study, this additional analysis has been conducted to explore further ideas presented by participants that were not captured in prior work. This analysis was driven by observations in the coding process of the original study analysis that were not explored previously and centred around the research questions:

**What distinct problem spaces do instrument designers consider to be involved in instrument design?**

**How do instrument designers define a digital musical instrument?**

This formed the basis for a research question motivating this analysis:

**How do digital luthiers approach design?**

## 3.2 Design

This study is built upon a qualitative method to provide deep and nuanced insight into the practice of digital luthiers. Reflexive thematic analysis (TA) is a powerful tool for human-computer interaction research which does not inherently include a theoretical framework such as grounded theory of discourse analysis [39, 10]. As such, Reflexive TA can offer flexibility for the researcher to define their research paradigm and apply a well-structured method to guide their analysis [11]. In this paper, we apply a phenomenological approach, exploring the personal perspective of digital luthiers and working inductively, focused on our interpretation of the participant's interviews, observing explicit semantic concepts introduced by participants, with some consideration of latent, underlying meaning where relevant. The study comprised standardised open-ended interviews, with 22 participants engaging with an interviewer via video call and five via email. Interviews were 20 - 60 minutes at the discretion of the participant. An ethical review by the University of West England's Computer Science and Creative Technology Faculty Research Ethics Committee was carried out ahead of the study, and all participants consented to participate.

The approach for the analysis in this work follows these steps:

- Data familiarisation period for reviewers
- Data coding using Quirkos software
- Deep exploration of data through previous analyses
- Themes creation
- Iterative reflection and development of themes
- Refining and naming themes, providing critical discussion and writing paper

The design of this study is provided in detail in the prepublication [33].

## 3.3 Data

This study used purposeful sampling to invite participants based on their contributions to a range of novel digital musical instruments or association with an organisation that produces instruments [12]. Participants were balanced according to a loose set of categories; Commercial, Research, Community and Artist with efforts made to also incorporate a diverse population, including gender, ethnicity, age and experience levels. Demographics are provided in the Appendix.

The data from this study is described in the prepublication [33] and publicly accessible via repository [1] to encourage using this data in future work. Some selected data is provided in the Appendix.

# 4. RESULTS

This study analysis focused produced four themes. It should be noted that these themes are not provided as some form of concrete experience or rule, but rather shared narratives that deepen the insight into digital lutherie as a practice. For example, themes one and two show two contrasting design approaches, where digital luthiers are close to evenly split in which approach they relate to most. As is developed in the discussion, while often themes one and two describe alternative approaches, there are examples of participants relating the two, alternating based on context or developing from one to another. All of these themes present ideas for further consideration and exploration by creating shared narratives that build ideas from participants' discussions.

## 4.1 Theme 1: Problem Solvers

In the discussion around digital lutherie practices, around half of the digital luthiers interviewed in this study described designing by starting with a concept or goal in mind, presenting an approach that works backwards from an intended outcome.

> But yeah, [maybe] You start with a specific question or problem that you have or wish for improvement on something *(P5)*
>
> We sort of come in with a with an idea, like, this is the it's this type of thing, something that works like this. That's the starting point *(P17)*

This approach tends to present a more methodological approach that has structured steps to reach a goal, often implying more planning, such as in the case of P7, who describes their sequence of steps, beginning with:

> - Choose concept based on gap in market, competitors product, innovative idea etc. *(P7)*

Often, where this approach relates to commercial applications, the participants describe targeting a particular niche or place within a marketplace. P9 and P19 describe examples of how they work back from design requirements and their environment, leveraging practices that ease mass production and work on the platforms they are targeting.

> I use elements in the design that are easy to fabricate with a lot of without high upfront costs. *(P9)*
>
> I tend to work backwards from the environment that they expect the instrument to be used in. *(P19)*

[1] https://github.com/muses-dmi/dmi-design-study

This goal-oriented approach is not only employed by more commercially motivated digital luthiers, however, and this theme is equally comprised of those whose motivations are primarily their own musical practice.

> A lot of the instruments that I've designed have have come out of working on a piece of music and saying oh well i want this sound [so that] then comes from necessity right *(P26)*
>
> So everything from my sort of design point of view, all comes from performance. *(P14)*

This is often framed by participants as fulfilling a need or targeting some form of deficit in existing instruments. However, this theme also captures the perspective of those who begin with other goals or concepts such as when P27 describes incorporating political messages and other values into the design of new instruments.

> So people are relating instruments now with political messages. And this is maybe one thing this is changing about concepts and values. *(P27)*

P24 describes a focus on form and the user interaction as a first priority.

> Second, the user interface - its layout later determines the functionality. It may sound odd, as one should rather start the other way around. But sometimes I prefer to invent a form first, then think about what could it do. *(P24)*

This theme broadly identifies an approach by which digital luthiers set out goals and then approach design as problem-solving.

> The case was I want something that, that that or behaves that way, how can I solve it? *(P1)*
>
> I really want to be able to go the other way. Like [having a range of sounds] I want to make, and then just like, Okay, how can I make that work... *(P17)*

This establishment of an initial problem implies the need for problem-solving skills. Interestingly, P11 suggests that this approach relates to experience with tools and technologies, describing how their practice moved from an approach better described by Theme 2 into the problem-solving approach described in this theme as their knowledge and confidence developed.

> Nowadays, I think I have a different approach, which is more like top to bottom, you know, and in that, that's probably also because I have a better knowledge of the tools, especially like hardware tools...
>
> I know, like many of these techniques, you know, I'm so so so I feel like now I can afford to think about an instrument, like at a very high level *(P11)*

## 4.2 Theme 2: Inspiration Seekers

In contrast to Theme 1, 'Seeking Inspiration' presents the approach to design that pursues inspiration from the technology, or more broadly, the materials used in digital lutherie. This approach was also discussed by around half of the participants and, in these interviews, is not clearly biased toward digital luthiers with specific motivations or backgrounds. This theme provides a narrative where digital luthiers seek inspiration for instrument design in their tools.

> And then from there, what felt really exciting to me was, [what] sensors are there, what are the are the kind of analogue tools that then can be converted into digital signal that then I can use to [control] my music software, and that's where it got really exciting and still remains really exciting for me is, is being able to then build controllers that are [in] as themselves kind of objects of curiosity. *(P14)*

P16 suggests that the approach described in Theme 1 cannot exist alone and that it is important to find inspiration in the technology that is used.

> it's fine to like, start an instrument making process being like, you know, I want to make a live coding instrument that allows me to live code faster. But you can't, you can't just like, write that in big letters in front of you, and then look at it every day for inspiration. *(P16)*

They advocate for a deeper familiarisation of materials in order to provide the instrument design process with direction.

> And kind of like deep familiarisation with the materials is also an add one of her principles. But I think those looking at it, from the process level gives you much more powerful kind of ideas of how to get somewhere with an instrument. *(P16)*

P4 relates to this by suggesting that these materials themselves have more influence on the outcome than they, as the digital luthier, have, where they may believe that these materials limit the outcome more than they have the power to influence it.

> I find that materials and instruments will inform me much more than I can inform them. So in that sense, I have to kind of allow for a system that will hopefully, allow me to to envision a different applications. *(P4)*

The need to explore the design space is described by many participants as a means for engaging with what is possible and not, given the available materials, a concept often framed in DMI literature as the interplay between an instruments affordances and constraints [26]. Digital luthiers directly appear to engage with this model during this exploratory process.

> I like new things. But I really need to understand what's available and what's not to define [what] movements and new is different from possible. *(P13)*

P23s practice includes the use and development of new tools for digital lutherie and looks to explicitly support the inspiring and exploratory nature of the design process.

> . . . because musician doesn't know the goal that they're going for, but they know what they're not going for. And so to imagine a tool or technology that can support that exploratory, but nonetheless focused process is is a real delicate, active both tool building an interface design. *(P23)*

This approach is not confined to the exploration of hardware and also demonstrated where software is the material of digital lutherie [5, 8, 6]. For example, P20 explores iterating around fragments of code and exploring the outcomes.

> I just sort of play - I write small examples, like SeqPal 0.1, that implement only the core of what I want, and extend them until they become unwieldy. Then I reorient with the new context and goals that I've come into. *(P20)*

## 4.3 Theme 3: Opinionated Designers

In their design practice, participants recognise a need for digital instruments to narrow the design space into focused artefacts that incorporate explicit choices.

> And then of course, like when you actually create a project, ie, you go from that kind of like vast spectrum that is very, like, continuous, and then you focus, like, I mean, in the concrete concretization of it, you will have to narrow down and like, make decisions about all of this. *(P3)*

Often this is realised through the call for ownership, even when working in teams, where an individual may facilitate focused and directed design choices.

> I still think that even if it's the team, there should be an owner, . . . so that even though [they] gather the inputs from all the people in the team. . . they are the ones that have the opinionated decision making rights.
>
> If that is not the case, then more often than not, you end up with a design by Committee, which is not opinionated, most of the case. And which often tends to become bland, and just general purpose *(P6)*

P6 effectively captures the desire for this owner to incorporate the opinions of others whilst driving toward feature sets that are curated and retain identity rather than being overly generic.

Whilst many participants call for clear ownership in design, this does not suggest that one person makes choices in isolation. Getting feedback and incorporating opinions is critical to many participants' approaches.

> And so it's kind of it really helps, like not having people, you know, not having people having to answer to your face, because like, they people don't want to offend you. *(P12)*

> the only aspects that is required to realise the design and implementation of the instrument like a, like, you always have to force yourself to remember that you're doing this for musicians. And, and that you're not doing it for yourself, to satisfy your needs to make weird tools. *(P11)*

> you know, the most important thing is to like, drop the idea when it's not good early *(P15)*

This is broadly recognised amongst participants, who also discuss how getting quality feedback remains a significant challenge.

> Another one that's really, really hard to get, that can be a help. Is, is a willing set of ears is, you know, sudden another musician who's willing who is willing to invest the effort it takes to think about an instrument which doesn't exist yet. *(P19)*

For some, continued feedback is achieved through integrating their own musical practice, performing and composing with both other instruments or the instrument being designed.

> Yeah, so my, like part of my music studio is very like dedicated to like testing the instruments that we build. *(P25)*

This is well exemplified by some participant's responses to the question, 'What tools do (or could) play the biggest part in helping with these challenges?'

> Having a cello? Really, I play every day and when I start my day playing cello I feel I did my job. *(P27)*

> Okay, it's probably a weird answer. But like, maybe the best tool is to keep playing music. *(P11)*

Cannon and Favilla [13] suggest that this ongoing performance and exploration is likely critical as expressivity might only be fully explored given sufficient investment in performance, meaning exploration in a continuous manner is a tool in evaluation.

Importantly the focused approach does not preclude accessibility. Instead, it can be prioritised and become a driving factor of opinionated design.

> Another critical part there, and that's sort of a recent concern of mine is , I'm very passionate about accessibility, which is a big issue with a lot of digital products in that people tend to focus on a subset of the population that is fully abled. *(P6)*

This does of course require proactive consideration from digital luthiers, demonstrating the value of having directed and deliberate ownership, where priorities of a given design can be managed. This has the potential to extend to many forms of accessibility and allows for digital lutherie to cater to many needs.

> You know, I don't, I'm not a big proponent of musical skill. I think it's more about the, the our familiarity with certain technologies than any kind of, I don't know, predisposition. ... we think that the [phenomenological feeling is] to have a musical intention and get there not just as quickly as possible, but as sort of thoroughly as possible, can my body do something that feels good, that makes a sound that feels good, and if those things match up with minimal friction, that's the best. *(P10)*

## 4.4 Theme 4: Interaction and Mapping

Digital luthiers indicated that their primary focus and challenge when designing DMI was the interaction between player and instrument, mapping interactions to sound. The relationship between gestures and the interface that is interacted with and how these relate to sound parameters were often described as simultaneously the most interesting and challenging component of digital lutherie.

> And mapping, for me, that's maybe off again for later, but mapping for me is is the most essential part of instrument design *(P4)*

> In the first instance, it was about ergonomics, and making something that was tactile, and like, sort of starting point was about finding a, like, you know, a tactile like and fun interface. *(P12)*

> An important aspect would be the relationship between the gesture and the sound, the gesture input and the sound output. One that is very organic and very intuitive. *(P23)*

> I think we have to consider that our ability to build control structures for musical instruments is just as much part of the instrument as the thing which makes the tone *(P19)*

Participants suggest that the emergence of complexity from mapping creates the quality of the instrument, where through mapping the instrument is far more than the sum of its parts.

> And you can have some very simple audio and some very simple sensors. But if you have nailed your range and parameter mapping, then it's going to, to be, it's going to work... *(P22)*

Participants also often consider the implications of interactions with the instruments, considering different perspectives such as that of the audience.

> And so if you abstract too much, then then you as the musician, or the audience doesn't even know where the sounds coming from. And so finding that that balance of intentionality, and ergonomics that you can trace, rather than just push a button or like move your hands around, and things happen, we're trying to kind of have a one to one relationship there *(P10)*

This extends to the point where some view the importance of control as often associated with the wider definition of a DMI, to the point where they describe the coupling of control and sound generation as defining a DMI.

> Like if you look for the definition of what DMI is, it always comes down to having something that has an interface separated from the place where a sound is being produced ... So to me, that's, that's always been a problem because if you disassociate the the, the interface from the place where sound is coming from, you might break the coupling or like the link between the two, you know? *(P11)*

> That is very rich. And so, if if we, in my case, mapping of human input to sentences output is the crux of the problem mapping can be thought of as a very direct thing, or a very indirect thing. And, Curiously, the most satisfying experiences, in fact come from direct mapping, but then they limit you ultimately, somehow get to more sophisticated forms of mapping that have the same satisfaction as direct mapping, but that that offer more in the asymptotic response or the instability. *(P23)*

This is not a unanimous view and is contrasted by those who lean into the opportunity of the fluidity afforded by the separation of the controller and sound generator, with P20 discussing how technologies can facilitate such design.

The, the, you know, the interface itself, the idea that you can abstract the gesture into many different outputs. And then, and then the idea that you don't have to choose just one way to play but that we can create interfaces that are that are multiple, and have have many different ways to sort of adapt to the player rather than the player just conforming to the instrument *(P10)*

But the way that I use supercollider is really like, easy for that. I mean, I've mentioned like, the use of multiple interfaces rather than just one. So I guess in a way, that is an answer to the question like the malts. Yeah. And kind of like interfaces that are multiple rather than a single object. And then he has supercollider because like I can sort of do go from micro patterning to more macro patterning and kind of like, operate with a single gesture, but on like different layers of where the meaning comes from. *(P3)*

The most interesting ideas in digital instruments come from considering how we connect things - through MIDI, as with SeqPal, or in terms of moving code around. Innovating in that space has made CircuitPython incredibly attractive. *(P20)*

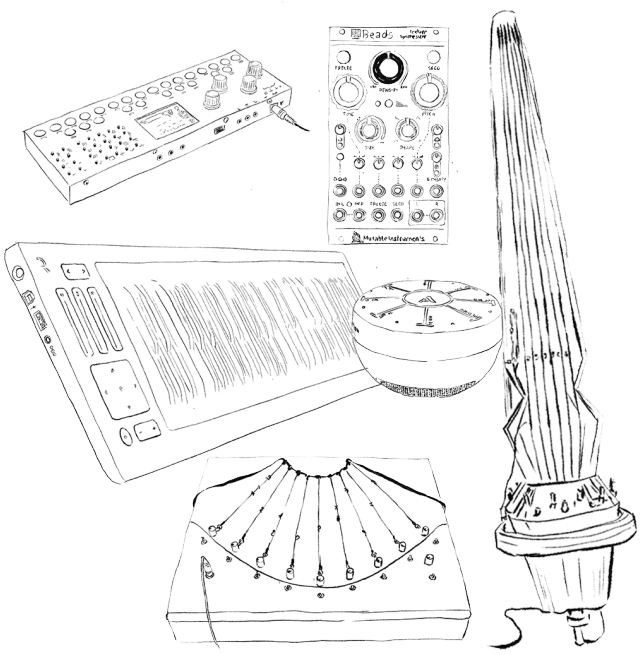


**Figure 3: Otto, Mutable Instruments Beads, Knurl, Roli Seaboard, Artiphon Orba, Electronic Khipu**

## 5. DISCUSSION AND FUTURE WORK

The analysis in this paper presents four themes that construct narratives that focus on distinct aspects of how digital luthiers approach design. While alone these ideas are insightful, when viewed together and within the context of existing work, we can develop further insights into the design processes of digital lutherie and begin to form hypotheses from observations that can be explored in future work.

Perspectives in Themes 1 and 2 suggest an interplay between learning from and being inspired by materials and problem-solving to reach an end goal. We see this described by P11, who says:

> So for a very long time, I had a more bottom to top approach where I would start from the hardware and its limitations and, and sort of try to build an instrument around the, around the hardware. *(P11)*

This might be viewed primarily in the context of Theme 2, which focuses on exploring the technology, directing and influencing the design process. As seen in Theme 1, however, P11 moves on to relate to a problem-solving approach. Through experience, P11 can focus on concepts and other goals as they design. This reflects research into the relationship between domain experience when designing software [1]. Due to the cross-domain nature of digital lutherie we suggest that Digital luthiers operate between two modes of design. In some instances, digital luthiers explore technology to find inspiration and familiarise themselves with their 'materials'[5, 2].

> I think experience and knowledge provides a lot of confidence and power, the knowledge is incredible because maybe I don't have the experience to resolve some questions but my mentors can see solutions in a short time, you can feel these big problem for you, are just small problem for other people making answers simple *(P21)*

Alternatively, digital luthiers work to problem solve in order to achieve a predetermined outcome or goal. These approaches can be viewed in light of what Adelson and Soloway [1] describe as depth-first and breadth-first problem-solving. This opens up an interesting channel of enquiry for future work to understand how digital luthiers alternate between these modes of operation. We hypothesise digital luthiers switch between exploration and problem solving in order to explore new domains as they arise, develop a familiarity with the affordances and constraints [26] of their materials and then problem solve in order to move toward their overarching goals.

In Theme 3, there is a clear direction and intention described in making DMI. Design is tightly focused rather than generic, with clear direction and ownership being a prolific strategy in DMI design. While this may seem a restrictive and exclusionary practice, we suggest that opinionated design is instead a powerful form of accessibility when approached correctly. For example, this would facilitate putting design for specific needs at the forefront of development by giving designers with those needs primary ownership over the design process [34, 31, 24]. As this study has also been used to explore the designer-tool relationship, we find that this perspective on design presented by digital luthiers further supports the role of end-user development in the implementation of DMI, empowering users to take ownership of the continued design of their instruments [32].

Finally, we observe that participants across the study heavily emphasised their interest in the process of mapping control to sound generation, a theme reflected in DMI research [28, 22, 40]. While due to the clear interest in this problem space, this observation is not surprising; it is affirming to see that through observational findings, this shared focus across research and practice is well aligned and motivates continued exploration in this area. Through mapping, digital luthiers seek to create more expressive instruments, which we suggest require expressivity to be reflected and embedded in tools, furthering a call for end-user development to be well factored into tool design for digital lutherie.

## 6. CONCLUSION

Given the themes developed in this paper, a narrative around the design process used by this group of digital luthiers is formed. These themes support and strengthen the NIME community's interests and suggest there is a great deal of opportunity to invest in deepening our understanding of how digital lutherie is approached. Analysis such as this, based on inductive research that can observe practice in the context of the deep and complex relationships it encompasses, is critical to the formation of new theories. By studying the practice of various digital luthiers, interesting lines of discussion are opened up. As we might presume from work shared through venues such as NIME, the domain of musical control, often referred to as mapping, is a key focus in the practice of digital lutherie and merits continued investigation and development. Opinionated design is also demonstrated as a core philosophy in the design of DMI, which we suggest with support from tools and the ecosystem can be empowering, increasing accessibility and democratising digital lutherie. Through our generation of themes, we also highlight the approach to designing DMI as an interplay between problem-solving and exploration of materials, where further studies might explore these modes of interaction and develop a better understanding of these processes.

## 7. ETHICAL STANDARDS

This work was ethically approved by the University of West England's Computer Science and Creative Technology Faculty Research Ethics Committee. Participants volunteered to take part following a call on forums, direct email correspondence and referral of peers and community members. All participants were provided an information pack detailing the study and the use of any data generated before participating and signed a consent form to take part. Participants had the right to withdraw at any time throughout the study and were also given a period to review their transcripts and redact any information before its publication.

## References


[1] B. Adelson and E. Soloway. The Role of Domain Expenence in Software Design. *IEEE Transactions on Software Engineering*, SE-11(11):1351–1360, Nov. 1985.

[2] J. Armitage, T. Magnusson, and A. McPherson. Studying subtle and detailed digital lutherie: Motivational contexts and technical needs. In M. Ortiz and A. Marquez-Borbon, editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 1–9, Mexico City, Mexico, May 2023.

[3] J. Armitage and A. P. McPherson. Crafting digital musical instruments: An exploratory workshop study. In T. M. Luke Dahl, Douglas Bowman, editor, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 281–286, Blacksburg, Virginia, USA, June 2018. Virginia Tech.

[4] J. Armitage, F. Morreale, and A. McPherson. The finer the musician, the smaller the details: NIMEcraft under the microscope. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 393–398, Copenhagen, Denmark, 2017. Aalborg University Copenhagen.

[5] I. Bergström and A. F. Blackwell. The practices of programming. In *2016 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*, pages 190–198, Sept. 2016.

[6] O. W. Bertelsen, M. Breinbjerg, and Sø. Pold. Emerging materiality: Reflections on creative use of software in electronic music composition. *Leonardo*, 42(3):197–202, June 2009.

[7] A. F. Blackwell. A craft practice of programming language research. In *PPIG 2018 - the 29th Annual Workshop of the Psychology of Programming Interest Group.*, London, 2018.

[8] T. Bovermann and D. Griffiths. Computation as Material in Live Coding. *Computer Music Journal*, 38(1):40–53, Mar. 2014.

[9] D. Braha and O. Maimon. *A Mathematical Theory of Design: Foundations, Algorithms and Applications.* Number 17 in Applied Optimization. Springer, Dordrecht, 2011.

[10] V. Braun and V. Clarke. Thematic analysis. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, and K. J. Sher, editors, *APA Handbook of Research Methods in Psychology, Vol 2: Research Designs: Quantitative, Qualitative, Neuropsychological, and Biological.*, pages 57–71. American Psychological Association, Washington, 2012.

[11] V. Braun and V. Clarke. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4):589–597, Aug. 2019.

[12] V. Braun and V. Clarke. One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, pages 1–25, Aug. 2020.

[13] J. Cannon and S. Favilla. The investment of play: Expression and affordances in digital musical instrument design. In *ICMC*, 2012.

[14] K. Dorst. Design practice and design research: Finally together? In *Design Research Society Conference 2016.* Design Research Society, June 2016.

[15] G. Fischer. Social creativity: Turning barriers into opportunities for collaborative design. In *Proceedings of the Eighth Conference on Participatory Design: Artful Integration: Interweaving Media, Materials and Practices - Volume 1*, PDC 04, pages 152–161, New York, NY, USA, July 2004. Association for Computing Machinery.

[16] G. Fischer. End-User Development: Empowering Stakeholders with Artificial Intelligence, Meta-Design, and Cultures of Participation. In D. Fogli, D. Tetteroo, B. R. Barricelli, S. Borsci, P. Markopoulos, and G. A. Papadopoulos, editors, *End-User Development*, volume 12724, pages 3–16. Springer International Publishing, Cham, 2021.

[17] G. Fischer and E. Giaccardi. Meta-design: A Framework for the Future of End-User Development. In H. Lieberman, F. Paternò, and V. Wulf, editors, *End User Development*, volume 9, pages 427–457. Springer Netherlands, Dordrecht, 2006.

[18] R. Frankjær and P. Dalsgaard. Understanding Craft-Based Inquiry in HCI. In *Proceedings of the 2018 Designing Interactive Systems Conference*, pages 473–484, Hong Kong China, June 2018. ACM.

[19] V. Goel and P. Pirolli. The structure of design problem spaces. *Cognitive science*, 16(3):395–429, 1992.

[20] A. Hatchuel and B. Weil. A new approach of innovative Design: An introduction to CK theory. In *DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm*, 2003.

[21] L. A. Hirschfeld and S. A. Gelman, editors. *Mapping the Mind: Domain Specificity in Cognition and Culture*. Cambridge University Press, Cambridge ; New York, 1994.

[22] A. Hunt, M. M. Wanderley, and M. Paradis. The importance of parameter mapping in electronic instrument design. In *Proceedings of the 2002 Conference on New Interfaces for Musical Expression*, NIME '02, pages 1–6, SGP, May 2002. National University of Singapore.

[23] S. Jordà. *Digital Lutherie Crafting Musical Computers for New Musics' Performance and Improvisation*. PhD thesis, Universitat Pompeu Fabra, 2005.

[24] M. Laura Ramírez Galleguillos and A. Coşkun. How Do I matter? A Review of the Participatory Design Practice with Less Privileged Participants. In *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 1*, PDC '20, pages 137–147, New York, NY, USA, June 2020. Association for Computing Machinery.

[25] S. Madgwick and T. J. Mitchell. X-OSC: A versatile wireless I/O device for creative/music applications. In *SMC Sound and Music Computing Conference 2013*, 2013.

[26] T. Magnusson. Designing Constraints: Composing and Performing with Digital Musical Systems. *Computer Music Journal*, 34(4):62–73, Dec. 2010.

[27] A. McPherson, R. Jack, and G. Moro. Action-sound latency: Are our tools fast enough? In *Proceedings of the International Conference on New Interfaces for Musical Expression*, volume 16, pages 20–25, Brisbane, Australia, 2016. Queensland Conservatorium Griffith University.

[28] E. R. Miranda and M. M. Wanderley. *New Digital Musical Instruments: Control and Interaction beyond the Keyboard*. Number v. 21 in The Computer Music and Digital Audio Series. A-R Editions, Middleton, Wis, 2006.

[29] F. Morreale, G. Moro, A. Chamberlain, S. Benford, and A. P. McPherson. Building a Maker Community Around an Open Hardware Platform. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, pages 6948–6959, New York, NY, USA, May 2017. Association for Computing Machinery.

[30] I. Posch and G. Fitzpatrick. The Matter of Tools: Designing, Using and Reflecting on New Tools for Emerging eTextile Craft Practices. *ACM Transactions on Computer-Human Interaction*, 28(1):1–38, Feb. 2021.

[31] R. Rajapakse, M. Brereton, L. Sitbon, and P. Roe. A Collaborative Approach to Design Individualized Technologies with People with a Disability. In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*, OzCHI '15, pages 29–33, New York, NY, USA, Dec. 2015. Association for Computing Machinery.

[32] N. Renney, B. Gaster, T. Mitchell, and H. Renney. Studying How Digital Luthiers Choose Their Tools. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, pages 1–18, New York, NY, USA, Apr. 2022. Association for Computing Machinery.

[33] N. Renney, B. R. Gaster, T. J. Mitchell, and H. Renney. Data and methodology : Exploring how digital luthiers choose their tools, July 2021.

[34] K. Spiel, K. Gerling, C. L. Bennett, E. Brulé, R. M. Williams, J. Rode, and J. Mankoff. Nothing About Us Without Us: Investigating the Role of Critical Disability Studies in HCI. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI EA '20, pages 1–8, New York, NY, USA, Apr. 2020. Association for Computing Machinery.

[35] N. P. Suh. Axiomatic Design Theory for Systems. *Research in Engineering Design*, 10(4):189–209, Dec. 1998.

[36] N. P. Suh. *Axiomatic Design: Advances and Applications*. The MIT-Pappalardo Series in Mechanical Engineering. Oxford University Press, New York, 2001.

[37] T. J. Tanenbaum, A. M. Williams, A. Desjardins, and K. Tanenbaum. Democratizing technology: Pleasure, utility and expressiveness in DIY and maker practice. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2603–2612, Paris France, Apr. 2013. ACM.

[38] L. Turchet and C. Fischione. Elk Audio OS: An Open Source Operating System for the Internet of Musical Things. *ACM Transactions on Internet of Things*, 2(2):1–18, May 2021.

[39] Virginia Braun and Victoria Clarke. Approaches to thematic analysis: Becoming a knowing researcher. In E. Rees, A. Ledger, and K. Walker, editors, *Starting Research in Clinical Education*. 2023.

[40] T. J. West, M. Wanderley, and B. Caramiaux. Making mappings: Examining the design process. In R. Michon and F. Schroeder, editors, *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 291–296, Birmingham, UK, July 2020. Birmingham City University.

# APPENDIX

# A. POPULATION DEMOGRAPHICS

| **Gender** | | **Ethnicity** | | **Age** | |
|---|---|---|---|---|---|
| Male | 14 | White | 21 | 18 - 24 | 1 |
| Female | 8 | Asian | 1 | 25 - 34 | 12 |
| Non Binary | 1 | Latinx | 1 | 35 - 44 | 6 |
| Prefer not to say | 4 | Brazilian | 1 | 45 - 54 | 2 |
| | | Prefer not to say | 3 | 55 - 64 | 4 |
| | | | | Prefer not to say | 2 |

**Table 1: Participant demographics (N = 27)**

# B. PARTICIPANT INFORMATION

| ID | Role | Experience | Instruments Created | Example Instruments | Languages |
|---|---|---|---|---|---|
| 1 | Music Technology researcher and professor. | 30 | 10 | FMOL, reactable (and many more) | C++, Pd |
| 2 | Owner of Mutable Instruments | 11 | 35 | Mutable Instruments Shruthi, Anushri, Ambika, MIDIpal, Eurorack line | C++, Python |
| 3 | Digital artist/performer/composer | 10 | 4 | Soft Revolvers, Ballistics, autopsy.glass | Supercollider, Max, Python, OpenScad, Touchdesigner, Processing, Javascript |
| 4 | Artist | 30 | 3 | Personal ones - the lady's glove, the Spring spare | Max MSP |
| 5 | Software Engineer | 6 | 3 | Polaron and other prototypes | C, C++, (Java / Javascript for non DMI work) |
| 6 | Software Engineering Manager | 11 | 8+ | Eigenharp, LinnStrument, GECO, Animoog, Model 15 App, Minimoog Model D App, Moog One, Claravox | Objective-C, C++, Swift, C, Bash, Python |
| 7 | CEO | 8 | 100 | Eurorack Modular, Desktop Synth, Effects Pedals, Audio Dev board | C++, Python, Csound, Arduino |
| 8 | Composer | 4 | 2 | No published products, tools for personal use | None in relation to this |
| 9 | | | | Linnstrument | C, C++ |
| 10 | CEO & Founder | 10 | 5 | Artiphon INSTRUMENT 1; Artiphon Orba; projects in development | C, C++, Apple Metal |
| 11 | Researcher and Lecturer | 10 | 20 | The BladeAxe, the PlateAxe, the Chanforgnophone, the Gramophone, Nuance, and many more. | Faust, PureData, C++, Objective-C, WebAssembly |
| 12 | CEO & Founder | 13 | 3 | AlphaSphere, BetaLoop, NUSIC | C++, Kotlin, Python |
| 13 | Assistant Professor of Music Technology | 11 | 8 | DMIs based on audio/visual physical modeling, hackable DMIs combinig digital and analog elctronics, immersive virtual DMIs, collaborative networked DMIs | C/C++, Assembly, GLSL, Pure Data; more rarely Super Collider, Max/Max For Live, C# [Unity], misc scripting languages |
| 14 | Composer & Instrument Builder | 10 | 20 | Lightdome, concertronica, eggiophone, the chromatic, the sonic bonnet and more | Arduino, Max |

| ID | Role | Experience | Instruments Created | Example Instruments | Languages |
|---|---|---|---|---|---|
| 15 | Software engineer / Audio developer | 6 | 5 | Ableton Live, Ableton Push, Ableton Simpler / Sampler / Wavetable | C, C++, Python |
| 16 | Researcher, designer, performer | 12 | 8 | ROLI Seaboard GRAND, Seaboard RISE, and Blocks, Stenophone, a series of "Unfinished Instruments" for my PhD. If you are counting DMI platforms: Bela | C/C++, JavaScript, Python, Haskell, SuperCollider, Pure Data, Bash |
| 17 | Software Developer | 4 | 1 | Mainly OTTO - a groovebox with synths, midi fx and audio fx | C++ |
| 18 | Professor | 20 | 15 | mainly physical modelled based | C, C++ |
| 19 | electronic musician | 40 | 12+ | a sample: 6502 based 8-bit instrument, Apple ][ based digital control for Serge Modular, Mac audio + MIDI software, RPi based effects unit + MIDI tools, MCU based metrical clock, MCU based looper + CV converter | Assembly, C, C++, Python, Haskell, Elm, Javascript, SuperCollider SCLang |
| 20 | Software Engineer | 1 | 2-3 | "SeqPal" and "DrumBud" for the Winterbloom Sol, and the Winterbloom Sol itself. | Python, Rust |
| 21 | Artist | 3 | 2 | Electronic_Khipu_ | Java |
| 22 | DSP Engineer | 4 | 5 | The Daïs, Magrittophone, several unpublished | C++, C, Python, Matlab, Faust |
| 23 | Professor of Media Computing | 35 | 5 | EMG instruments like the BioMuse and the EAVI EMG, and have made musical instruments out of consumer devices like the Thalmic Labs Myo | C, C++, Python |
| 24 | HW and SW engineer | 3 | 6 | Gechologic Loopsynth, Phonicbloom's Glo Polyphonic Whale, MMXX Tape, Wingdrum, Loopstyler, Don Iguano | C/C++, Python, php, Javascript |
| 25 | Lead designer | 12 | 30+ | the whole Bastl Instruments product line | C++, Arduino |
| 26 | Composer and interactive hardware developer | 15 | 10+ | Custom interfaces for live performance | Max/MSP, Supercollider, Arduino, Python, Lua, Rust |
| 27 | Creative director | 2 | 1 | Knurl | C++, Supecollider, Javascript |