Digital Musical Instruments as Research Products

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ABSTRACT

In the field of human computer interaction (HCI) the limitations of prototypes as the primary artefact used in research have been noted. Prototypes often remain open in their design, are partially-finished, and have a focus on a specific aspect of interaction. Previous authors have proposed 'research products' as a specific category of artefact distinct from both research prototypes and commercial products. The characteristics of research products are their holistic completeness as a design artefact, their situatedness in a specific cultural context, and the fact that they are evaluated for what they are, not what they will become. This paper discusses the ways in which many instruments created within the context of New Interfaces for Musical Expression (NIME), including those that are used in performances, often fall into the category of prototype. We shall discuss why research products might be a useful framing for NIME research. Research products shall be weighed up against some of the main themes of NIME research: technological innovation; musical expression; instrumentality. We conclude this paper with a case study of Strummi, a digital musical instrument which we frame as research product.

Author Keywords

Research products, in-the-wild, prototypes, research probes, design theory

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts; •**Information systems** → *Music retrieval;*

1. INTRODUCTION

Much NIME research is driven by the exploration of novel technologies applied to the musical context. One interpretation of the 'new' in NIME is that it represents a belief in new technologies opening up new means of musical expression, and leading to the creation of new music. This largely depends on advancements in the core technology that underpin instrument making, and hence an instrument's functionality and ability to create music. Another main strand of NIME considers the agency of musical instruments within a musical context and their influence on a performance ecosystem [22]. This division is key to what we outline in this paper as *research prototype* and *research product*.

We argue that a significant number of the interfaces, instruments and artefacts created as part of the research conducted at NIME are imagined as research prototypes: their deployment and evaluation encourages people to reflect on the qualities of the instrument and to suggest limitations or possible improvements to the instrument. Prototypes direct people to think about the artefact as a demonstration of a principle that points towards a future revision [13].

Odom et al. define *'research products'* [19] as an extension of the prototype which allow us to better focus on the complex factors that are brought together in human-computer relationships. In short, research products are a type of artefact in HCI and design research, which match the level of fidelity often seen in commercially available and everyday objects, as opposed to the explicitly 'unfinished' nature of a prototype. This property allows research products to be taken *'for what they are, rather than what they might become'*, and for researchers to investigate *'complex matters of human-technology relations that often involve messy, intimate and contested aspects of every day life'*.

In this paper, we introduce the concept of research product, and evaluate how it can be applied to NIME research. We shall conclude this paper with a reflection on Strummi, a digital musical instrument (DMI) which we characterise as research product.

2. CONTEXT

Prototypes play an important role in both HCI and DMI research. The prototype can allow researchers to focus on a particular aspect of interaction, isolating it from its surrounding context, and can inform developments of a technological system that improve its usability and a users' experience. Prototypes are also often quick and cheap ways of testing an idea.

2.1 Prototype, Probe, Product

Prototypes play a crucial role in the crafting of an artefact: certain questions about an artefact's design, particularly those that relate to tangible experience, are best answered through observing interaction with a semi-finished artefact that has enough of its design in place as to guide the interaction of the user. Based on observation of this interaction the designer can hone their future decisions to better cater for the kind of experiences that they want to encourage through their design. In this sense, prototypes serve to elicit feedback from the people who use them with the goal of improving their design in the future [19]. The role of the prototype is often understood as a means of helping gather requirements that will inform future designs, whether these requirements are specifically known or not [13].

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Where prototypes may fall short is in their ability to address more complex issues about how a technological device intervenes in everyday life and how the device itself is conditioned and appropriated by its surrounding context. Prototypes vary in their fidelity. Some are component parts of a bigger system, others are a full system but are low-fi or approximate in certain ways: differing in size, finish, behaviour and feel from a potential final product.

2.1.1 Technology Probes

When considering the process of co-designing technologies with users the method of the 'technology probes' by Hutchinson et al. [10] provides a useful extension of the prototype. Building upon Gaver et al.'s 'cultural probes' [5], technology probes are defined as lo-fi devices, whose main technological hurdles are solved, which can be deployed in an everyday situation to gather information about technology use in that situation. They are created in order to serve three goals: the design goal of inspiring users and researchers to think about new technologies, the engineering goal of field-testing the technology, and the social science goal of understanding the needs and desires of users in a real-world setting.

Probes get their name from their ability to 'probe' a certain situation and gather information on it. They at once disrupt an everyday situation and then monitor what happens after that disruption. Technology probes are not designed to be neutral or invisible devices that can gather objectively without interfering in an everyday situation. In fact the power of the technology probe methodology comes in the recognition of the disruptive impact of a design, and in using this disruption to inspire users to reflect on the technology and their situation and to imagine possible future technologies. In this way technology probes are similar to the 'counterfactual artefacts' as proposed by Wakkary et al. [21]. Equally, as a research methodology which focuses on deploying design artifacts in-the-wild in order to learn something about that environment, technology probes have much in common with research products.

2.1.2 Research Products

Odom et al.'s 'research products' [19] is a response to the use of 'unfinished' prototypes in design research:

> *'The complexities and challenges in researching questions about human-technology relations in everyday life ... suggest that the notion of a 'prototype' within research may not be sufficient' [19]*

They define a research product as an artefact which is experienced based 'on what it is, rather than what it might become'. This is about the design, deployment and evaluation of research artifacts. They define the qualities of a research product as follows: *inquiry driven* (they are designed to provoke users in their environment and to engage them in an enquiry, but not necessarily one that relates to the artifact's design), *finish* (their design is complete and interaction is predicated on what the artefact is as opposed to what it might become), *fit* (they must be able to fit into an everyday scenario and in a convincing manner) and *independent* (they can be deployed in the field and have the potential for unsupervised interaction).

Research products as a design concept are a means of revealing how human-technology relations emerge and change over time in everyday life. A critical distinction between the nature of prototype and product is that all design decisions including those related to 'material, form, computation and interaction' affect an artefact's ability to conduct research: the particular manifestation of these qualities of an artefact decide on the precision to which research questions can be asked [19]. Research products are emphatically distinct from commercial products - we are not interested in their commercial potential or how many copies have been made: they are only designed to fulfil a research inquiry. Any similarities with commercial products would only arise from the shared goals of producing 'finished' artefacts that can be easily imagined being adopted in real-world settings.

2.2 Prototypes in NIME

There is a focus in much DMI research on the functional elements of an instrument as research contributions (sensors, mappings, sound model) even though there are many other aspects of a design that affect performer experience. Due to this functional focus, the prototype is the most common form of research artefact at NIME. Prototype instruments often stand in as a demonstration of a principle and the types of evaluation conducted with these instruments often encourages people to reflect on the qualities of the instrument and to suggest limitations or possible improvements. Specifically, the iterative nature of NIME design and evaluation can lead to a focus amongst designers, performers, composers and audience on how an instrument might change or evolve, rather than be treated as a finished artefact.

Prototypes are essential research tools for many areas of enquiry relating to DMIs. In this paper we are interested in how we can best categorise the research motivations of instrument building which includes the creation of the artefact itself, its design process, deployment and evaluation. In a recent paper by Morreale et al. [18] some of these motivations were surveyed in the NIME community asking questions about uptake, number of performances and initial reasons for creating an instrument. 32% of the surveyed instruments were created with potential commercialisation in mind with the rest intended to answer specific research questions, test new technologies or meet an artistic desire of the creator or collaborator.

The evaluation of a prototype is often focused on the artefact itself rather than the environment in which the artefact is deployed: NIME evaluation methodologies in general borrow heavily from HCI experimental design where a single variable is tested in a controlled situation. However when dealing with a cultural form as rich and complicated as a musical instrument finding the right evaluation framework is a difficult task [1].

2.3 Towards DMIs as Research Products

There exist several examples of *technology probes* in music HCI, including explorations of how an acoustic guitar can contain its own history through a digital archive that it builds around itself [2], and studies on the appropriation of highly-constrained musical instruments [6]. We see research products as a natural counterpart to the technology probe approach. The differences in physical properties of what is considered a probe or product might be subtle, or even non-existent, but we see the research product approach as a 'zooming out' to observe the entire ecosystem around musical instrument playing, rather than probing a particular aspect of instrument design.

Importantly, research products place an equal emphasis on non-technical design choices such as materiality, 'feel', and visual aesthetics, alongside the more technical questions of sensor technology, mappings, and sound-design. Referring back to Odom et al.'s qualities of a research product, we discuss how this might transfer to NIME:

Inquiry Driven: This is a quality of research products that we do not need to argue for in NIME - there is a tradition of inquiry-driven designs in NIME research, with examples of DMIs designed to explore phenomena of

human-instrument interaction such as style and constraint [6], action-driven interaction [20], and control intimacy [23]. Research products continue this tradition of inquiry-driven design, but due to their other qualities can be more appropriate for addressing the 'messier' questions concerning the sociocultural role of musical instruments in everyday life.

Fit: This considers how an instrument fits into an existing sociocultural context. This does not preclude experimental or novel aesthetics, however an instrument cannot be considered as detached from the wider societal context it is part of. Research products aim to delicately balance between being *'neither too familiar nor too strange'* to the scenario in which they are deployed. When considering 'fitting' into a musical context leveraging existing technique, whether trained or ecological, and addressing existing musical practices is key.

Finish: This is where Odom et al.'s research products begin to depart from the values inherent in NIME research and DMI design in general. Odom writes that the choice of materials and level of finish 'makes clear the commitment of the artifact as a finished object' [19].

This suggests a level of 'finality' to an instrument that runs counter to performance contexts where the instrument is widely understood to be constantly evolving, for example where the DMI performer is also the designer, who reconfigures and adapts their instrument over a considerable period of time without the goal of reaching a 'final version' or even any notion of 'improvement'. This can be seen in contexts such as modular synth performances, where a functionally complete instrument exists, but potentially only for a single performance before being rearranged, simplified, or updated. This raises a pertinent question for NIME research about when an assemblage of technologies becomes an instrument. We suggest that labelling an instrument a 'research product' need not set anything in stone in order to achieve a level of 'finish': it is more a question of the instrument being taken as a viable instrument in the here and now of its performance context.

Independent: Research products are designed to be lived with independently. This methodology is predicated on the assumption that the designer is different from the performer. In NIME we often find situations where the designer, composer and performer are the same person which can give great insight into how these disciplines combine, but can limit the reach of research conducted with the instrument to audiences the performer directly engages.

3. CASE STUDY: STRUMMI

To provide an example of the *research product* and *technology probe* methodologies in practice within DMI research, we present a case study of a series of guitar-like DMIs we have called *Strummi*. We designed seven different variations of Strummi over two generations. While the technology inside each variation remains broadly the same, the overall material form and method of interaction with each version was intended to address a number of different inquiries.

The first generation of Strummi instruments were presented in [8] and [11], focusing on the role of global form vs. interaction modality, and richness of interaciton, respectively. The early stages of a later research project involving more recent variations of Strummi are detailed in [7].

3.1 Rationale for Design

Our goal with Strummi was to design a research artefact capable of addressing the *cultural form* [9] of guitar-playing, and how that might relate to new guitar-based DMIs. In particular, we wanted to see how guitar-based Accessible

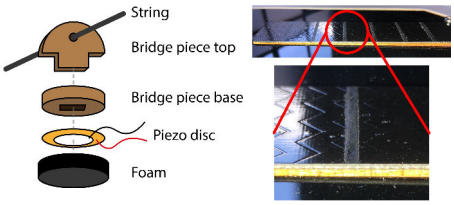

Figure 1: Left: construction of the bridge pieces for the 'strings' instruments. Right: touchstrip with tactile paint strip for the 'touch' instruments

DMIs (ADMIs) might fulfil the social and cultural role of guitars in an existing performance ecosystem. Accessible Digital Musical Instruments (ADMIs) is a growing research area (see [4]). A number of accessible guitar-based ADMIs have been developed, including the Kellycaster[1], Actuated Guitar [12] and guitarMasheen [16].

In addition to guitar-based DMIs designed to address a particular access need, there are a growing number of both commercial- and research-based guitar-like DMIs, including MIDI controllers such as Artiphon's *Instrument 1*[2] and Roger Linn Design's *Linnstrument*[3] provide a fretboard-inspired note layout with MPE MIDI for individual note-level expression for vibrato and slides.

We considered that components of the *cultural form* [9] of guitar-playing - the choreography, the visual appeal and aesthetics of guitars, the mimickry of role models in popular culture - were both significant and under-explored in the context of DMI research. The prototype instruments that we created in the first place were aimed at answering questions related to this cultural form, whether about the actual morphology of the instrument itself, or about the degree of control a performer has over that instrument.

3.2 Building Strummi

The principal idea behind the Strummi instruments is to reproduce the physical action of strumming and plucking a guitar, while simplifying the action of chord selection or fretting to a push-button, similar to that of an Autoharp or Omnichord. We developed two methods for strumming: *strings* and *touch sensor*. We also initially came up with two different form factors: *guitar-like* and *tabletop* (see Table 1) .

3.2.1 Hardware

The *strings* version of Strummi feature six short lengths of .40 gauge guitar string threaded through individual wooden bridge pieces with integrated 15mm piezo disc sensors (see Figure 1). This method maintains a tight mechanical connection between the string and the piezo disc. A layer of foam beneath each disc provides a degree of acoustic isolation between adjacent strings.

The *touch* version uses a rectangular Trill capacitive touch sensor [4] which is capable of detecting multiple touch positions along its length. In the software, we defined six equally spaced points along the length of the sensor where a note would be triggered on receiving a touch input. To provide tactile feedback, we applied several layers of paint to the sensor where these note triggering points occur (see Figure 1). 'Strumming' and 'plucking' the touch sensor is anal-

[1] https://www.drakemusic.org/technology/instruments-projects/the-kellycaster/
[2] www.artiphon.com
[3] www.rogerlinndesign.com/linnstrument.html
[4] https://www.kickstarter.com/projects/423153472/trill-touch-sensing-for-makers

	Strings-guitar: Custom guitar body enclosure with chord buttons embedded in neck. Designed to emulate guitar-like choreography and playing style		Touch-guitar: Custom guitar body enclosure, with touch sensor in place of strings (triggers samples when tapped or swiped)
	Touch-tabletop: Tabletop enclosure with touch sensor - design inspired by boutique electronic music hardware such as Buchla controllers		Strings-tabletop: Tabletop enclosure with strings

Table 1: Strummi as Technology Probe: First generation Strummis designed for lab-based study on instrument form and interaction modality

ogous to swiping and tapping a touchscreen device. All Strummis feature push-buttons to select chords. Pressing a button results in each of the six virtual strings being tuned to a preset chord voicing in the key of G Major.

Strummi uses a Bela Mini board[5], an open-source platform for audio and sensor processing [15] which includes a Pocket Beagle embedded Linux computer[6] for processing and ultra-low latency action-sound capabilities. The piezo discs were attached to the analog inputs of Bela via a simple voltage biasing circuit. The analog inputs on Bela are sampled at 22 kHz 16-bit allowing the signals to be treated as audio signals throughout the DSP chain.

3.2.2 Form Factors and Materials

For a more detailed description of the rationale behind the various form factors of the first generation of Strummis, see [8]. To summarise, we wanted to compare the effect of a design which closely emulated both the aesthetic properties and the playing style of a guitar, versus one which was more comparable to tabletop music hardware.

From the outset, we intended to design research artefacts which would be accepted by potential users as 'finished' instruments. Further to this, we were keen to ensure that Strummi would maintain a sense of 'cultural acceptability' - in other words, that it would *look* and *feel like* an instrument that would plausibly be used in the cultural context of strummed string performances, such as in a folk session. These goals affected our choices for materials and overall aesthetic qualities, including the hardwood guitar-inspired enclosure used in the first generation of Strummi (see Table 1), and later the modified Les Paul guitar (Table 2).

3.2.3 Sound Design

The Strummi instruments use a basic implementation of the Karplus-Strong plucked string algorithm to simulate the harmonics and decay of an acoustic string. This synthesis method is typically excited using a burst of noise to simulate the initial onset of a plucked string, however with the Strummi instruments, we used two methods for exciting the string model: *sample triggering* and *audio-rate excitation*. For *audio-rate excitation*, we directly excite the Karplus-Strong model with the audio signal from the piezo disc. This technique of exciting string models with an audio signal has been used in instruments such as the *Kalichord Strum*[7], *BladeAxe* [17] and *tangible virtual vibrating string* [3]. The effect of this approach is a strikingly realistic simulation of a full-length vibrating string: as the acoustic signal from the piezo sensors is used to drive the Karplus-Strong model, the nuances in the way that the dampened strings are interacted with are preserved in the resulting sound.

3.3 Strummi in Research

To date the seven versions of the Strummi instruments have been used in two major research projects. Throughout this period we have revised the design and made minor modifications which are detailed below. The evolution of our designs were targeted at different research goals, and with this evolution has come a changed conceptualisation of the instrument, from research *probe* to *product*.

3.3.1 Strummi as a Technology Probe: Lab-based Comparative Study

The initial study and its results are discussed in [8, 11]. Inspired by the research probe methodologies as discussed in 2.1.1, we developed a set of instruments with the specific intention of provoking reactions through its design in relation to global form, input modality, and richness of interaction. Our study methodology was a time-limited, lab-based and highly structured experiment in which participants were directed to complete short musical tasks on two Strummi instruments out of a possible four design variations. Each performance section was followed by a questionnaire and interview comparing the two instruments used. In this way, we intentionally disrupted the participants' conception of what Strummi was by offering a broadly similar, but significantly modified version to compare against.

What defines Strummi as a technology probe, rather than prototype or research product, is that in this instance Strummi serves as an explicit provocation to participants' ingrained notions of 'guitar-likeness'. We were not looking to future Strummis based on findings or feedback from the study participants, nor were we deploying Strummis in the wild to observe the human-instrument interaction over time.

3.3.2 Strummi as a Research Product: an In-the-wild Study on Accessibility

[5] http://bela.io

[6] http://beagleboard.org/pocket

[7] https://blog.bela.io/2017/05/15/kalichord/

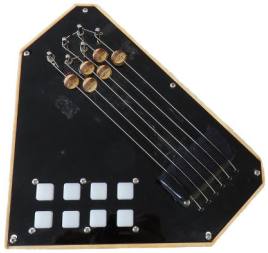		
Re-design of original tabletop Strummi with eight silicon buttons to replace original pushbuttons	Re-design of guitar body enclosure to reduce size and weight. Design inspired by Les Paul guitar body shape, built with same materials as tabletop instrument	Les Paul-style electric guitar, modified with Strummi hardware in the body. Push-buttons installed in neck in position of top two frets.

Table 2: Strummi as Research Product: Second generation Strummis designed for in-the-wild study

The follow-up study saw three Strummi string instruments deployed through a longitudinal and situated research partnership with a creative arts charity for people with learning disabilities (*Heart n Soul*[8]). Over the course of a year, we introduced the first generation Strummis to a group which took part in monthly jam sessions using electric guitars, basses, drums and keyboards. The participants in this group have a wide variety of access needs stemming from physical impairments, learning disabilities and neurodivergence. From our first meeting, we observed that for some members of this group, Strummi possessed accessibility affordances due to the reduction of chord selection to a push-button interface, whilst maintaining the responsiveness and acoustic properties of the strumming interaction.

Our goal with this study was to observe the importance of these potential accessibility affordances over other factors such as the global form and aesthetics of Strummi, the familiarity of other instruments, and the role of environment and social context in enabling access to music making. Early reflections on this deployment are discussed in [7]. This project concluded with two additional jam sessions - called the *'Strummi sessions'* - which were audio and video recorded, followed by a semi-structured group interview.

The early stages of this project highlighted usability issues with the original Strummis. These included the weight of the 'guitar body' enclosure, which made playing for long periods uncomfortable, and inaccessible for many users with mobility issues. We also noted that the push-buttons used in the first generation were prone to mechanical failure. Finally, the use of a 3.5mm headphone output meant that Strummi could not easily be swapped with an electric guitar when using a standard guitar jack lead.

Prior to the Strummi sessions, we designed a second generation of Strummis which addressed these issues (see Table 2) We redesigned the 'guitar body' Strummi to be lighter and built with the same materials as the tabletop version, modifying the shape to resemble a the classic Les Paul body. We also went one step further towards 'guitar-likeness' by modifying a Les Paul-style electric guitar with Strummi hardware in the neck and body to create a further artefact.

The material changes to the second generation Strummis did not affect the functionality or sound of the instrument, but were significant from a research product standpoint. In particular, the switch from the 3.5mm headphone input to a 6.35mm guitar jack made no impact on the sound of the instrument, but allowed it be swapped easily between the electric guitars already in use at the monthly jam sessions. Part of our inquiry was the question of whether guitar-based ADMIs could adopt the cultural form of electric guitar playing in order to provide access to guitar performance for those for whom unadapted electric guitars are inaccessible. Our choices in form, materials, and connector types implied an equivalence between Strummi and the electric guitars which allowed us to observe people's interaction with both instruments on an equal footing - we didn't have to ask the users of Strummi to 'imagine it being a finished instrument' in order to compare it with the guitar.

The key difference between this second study and the first is the move out of the lab and into a situated, longitudinal and ethnographic approach. We were no longer concerned with directing the participants of our study towards defined musical tasks, or otherwise compelling them to make direct comparisons between the different versions of the instrument. In other words, we were no longer 'probing' the effects of the different versions of Strummi, but as much as possible aimed to act as passive observers of interactions with Strummi in an everyday setting.

It is worth noting that even without material changes, our shift in research methodology was significant in reframing Strummi as a research product. This move from a lab-based study to a situated ethnography-informed approach moved us to consider ways in which the Strummi instruments could help us answer broader questions of accessibility in guitar-based ADMIs, as well as consider its independence and ability to be 'lived with' in a real world setting.

4. CONCLUSIONS

This paper serves as an introduction to research products and partial exploration of how they fit within NIME. We have left many implications of DMIs as research products unexplored and invite future researchers to contribute to and develop this idea. A particular tension that warrants further discussion is how 'finished' research products sit alongside the explicitly unfinished and exploratory process of participatory design - especially in relation to ADMIs.

The research product approach is of potential benefit to DMI researchers interested in observing the relationships between instruments, their players, their audience and their environments. Part of its value comes from recognising that prototypes, although essential when crafting musical interactions, are necessarily limited in their research scope. There is an opportunity for more NIME work to fit into the research product category, allowing the consideration of interactions with new instruments based on what they are rather than what they might become. The notion of

[8] www.heartnsoul.co.uk

'finishing' a new instrument however runs up against certain community values in NIME which both push towards a prototype approach. What exactly *finish* might mean in relation to NIME does not entirely equate to a sense of material 'completeness' but rather highlights how instruments can be considered as realised through their performance. A research product here may be better framed as a product of a specific and evolving music ecology. Finish could be considered as both an attitude towards an instrument being functionally complete within a performance context, as well as the material and aesthetic qualities that lend the instrument its ecological validity.

NIME's tendency to focus on specific technological contributions such as technical novelty and new uses of sensors as the locus of contribution stands as a barrier: aspects such as the material finish of an artefact do not have a position in this kind of research. This was previously discussed in the NIMEHub workshop [14] as a limitation of sharing design knowledge through technical papers. Research products argue for taking aspects of a design such as materiality and finish as seriously as technological aspects.

These points also apply to the question of evaluation in NIME. The nature of our evaluation methods has long been a concern for NIME researchers [1]. A move towards research products in NIME would mean considering instruments more as situated, ecologically valid artefacts. Importantly the research product methodology is inclusive of the method of deployment and evaluation as well as the design of the instrument. Research products recast 'evaluation' as a qualitative and reflective process focusing on sociocultural phenomena, rather than quasi-scientific methods based on first-wave HCI techniques. Research products offer a complimentary methodology that can help access the nature of interactive technologies in everyday life.

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