pegBits: Experimenting with a 0.1” System for Open Hardware Prototyping

Jon Rogers
School of Design
Northumbria University
Newcastle upon Tyne, UK
jon.rogers@northumbria.ac.uk

Justin Marshall
School of Design
Northumbria University
Newcastle upon Tyne, UK
justin.marshall@northumbria.ac.uk

Jayne Wallace
School of Design
Northumbria University
Newcastle upon Tyne, UK
jayne.wallace@northumbria.ac.uk

Tom Metcalfe
School of Computer Science
University of St Andrews
St Andrews, UK
tjbm1@st-andrews.ac.uk

Nick Taylor
Open Lab
Newcastle University
Newcastle upon Tyne, UK
nick.taylor@newcastle.ac.uk

Romit Raj
Quicksand Design Studio
Bangalore, India
romit@quicksand.co.in

Jayn Verkerk
School of Design
Northumbria University
Newcastle upon Tyne, UK
jayn.verkerk@northumbria.ac.uk

Philip Heslop
School of Design
Northumbria University
Newcastle upon Tyne, UK

Abstract

In this paper we introduce a work in progress prototyping system for constructing 3D prototypes to house open hardware electronics. The system, called pegBits, takes the standardised 0.1” hole separation found in 2D perfboard and breadboards and extends it to a construction system in 3D. We describe our motivations for doing so that includes: making prototyping more accessible, taking a designerly and crafty approach to prototype design and searching for the elusive space between off-the-shelf and custom designed. We show our development and present a series of reflections on the ways we can make prototyping with open hardware more accessible to the communities of practice that we engage with.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**.

Keywords

Prototyping, Open Hardware, Design, Craft, Electronics, Making

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1 Introduction

For many of us, some of our earliest memories will come from modelling the physical world through lines of Meccano or blocks of Lego and playing with electronics kits like 160-in-1. Blocks were the learning ground for how the world works and for many the start of a lifelong commitment to modelling, making and building. In the TEI community, these early experiences have influenced the way we approach computing, inspired by visions of tangible bits [9] and physical computing [20].

Bringing physical computing to life has required being able to develop not just code, but the electronics and physical form that bring the digital into the physical world. Open platforms like Raspberry Pi (launched 2012), Arduino (founded in 2005) and Limor Fried’s Adafruit (founded in 2005) have taken huge steps towards making electronics more accessible for designers and amateurs. Thus enabling them to push back against closed systems that make devices less transparent. Digital fabrication, especially open-source options like RepRap [10], alongside maker communities and accessible facilities like makerspaces and FabLabs, have taken steps towards making physical prototyping equally accessible. Yet, while these platforms have developed in leaps and bounds, they remain hard to use for everyday people [12, 17]. 3D printing and digital making in general are powerful tools bridging between bits and atoms, but also remain for the most part illusive to community members lacking product design and CAD engineering skills [18]. This creates a tendency towards reproduction rather than creation.

For this work-in-progress describes our attempt to establish a system of building that integrates electronics into the physical world in a way that affords adaptation and construction with the standardisation and constraints of building blocks, while allowing electronics to remain in an established and recognisable form. We introduce pegBits, a system of building that is analogous to the

Figure 1: The hiCam family.

nature of the established standardised forms of electronics. pegBits integrate physical computing into the physical world akin to how Meccano or Lego afford adaptation and construction through utilising standardisation and constraints. We describe the start of the journey of pegBits and draw on the experiences of the first author in the process of the development of this idea. We share the motivation of the idea, design development and first author reflection on challenges and opportunities in attempting to create pegBits as a missing piece that is situated between unconstrained and standardised prototyping.

1.1 Between Unconstrained and Constrained Prototyping

Systems of standards to allow structured design are well established in electronics prototyping. In the 1960s, Bell Labs developed a standard for mounting components with holes 0.1 inches apart [5], instantly recognisable on perf board and breadboards. There are a number of electronic prototyping systems that build on this standard, for example littleBits' perf Bit [15], Lee et al's [13] Virtual Wire and Adafruit's Swirly Aluminum Mounting Grid [8]. Other systems have gone further to widen access to electronics: littleBits [1], inspired by Lego, is an example of proprietary systems that boxed up electronics as modules/components to simplify construction, and removed the need for programming. It has a number of applications in teaching technologies in the early years [14]. The intention of such simplified block systems are for teaching and learning through prototyping the behaviour of electronics and the physical world, rather than the design and form of the prototype in the physical world.

Chatting [3] alludes to the potential to extend the form of the breadboard beyond the circuit in his pegboard mounted circuits as part of his designerly hacking approach. He specifically builds on the affordances of the pegboard to signify that components can be easily reconfigured. Framing invitation to change designs, as Pace Layer Design; an approach that he links to the practice of Research Through Design (RtD) [6] and the development of Research Products [19]. Gaver et al's [7] Yo-Yo machines are an example of an RtD approach to lay user-generated connected research products. They were developed as a way of exploring social connectivity during the Covid-19 pandemic. The electronic kits were constructed by participants using breadboards to house the small number of components. The physical housing was left to a participant's own design, with users encouraged to up-cycle found objects to house the kits (iPhone boxes were found to be particularly useful).

Building on and taking inspiration from this work, pegBits aims to extend the type of standardised system seen in electronics into 3D prototyping in the physical world. Our intention with pegBits was to design a construction system for makers who want to engage with active prototyping, but to go a stage beyond the breadboard and projectbox to represent an invitation to designerly prototyping of open hardware. One that occupies the kind of space that Chatting [3] proposes as an extension to 3D prototyping.

2 Motivations

In developing pegBits there was no single criteria that we wanted to follow, but rather a set of inspirations and motivations that came together to prompt us to develop a distinctive approach, which we now list and describe.

- **Simplifying bespoke prototyping** with a Raspberry Pi. Cases for the Pi have been a popular endeavour for the maker community: at the time of writing, there are 5,550 designs tagged as Raspberry Pi cases on Thingiverse [22]. These are hugely varied and bespoke, ranging from computing nostalgia (Pi SNES, Mini Tower) to problem solving applications (Pi Zero Camera Holder, DIN rail mount, rack mounting). However, all of these are complete solutions, rather than a system for doing what commonly happens with a Pi: experimental prototyping. Printing an existing solution can take several hours, but designing and printing a unique solution can take days and may be beyond the skills of many Pi users.
- **Designing for others to adapt**, specifically non-technical colleagues and collaborators, who had significant skill and experience in craft and making, but little or no expertise in electronics or code. Designing for others to adapt and customise in a designerly way was needed for our wider team to engage in making physical/digital objects together. Although the initial motivation was for our own use, but we anticipate that there might be potential for a much broader audience also.
- **Appreciating and utilising the constraints we had**. There is something enticing about working with possibilities within a constrained space. Whether that's on a breadboard, with

a Lego set or a fixed set of cooking ingredients. A motivation for us was to find a balance between open prototyping with its limitless possibilities and steep learning curve (for example CAD and 3D printing) and closed prototyping (i.e. Thingiverse Pi case), which features ease of use but offers a limited canvas.

- **Needing to include ventilation** on the back of the device led us towards exploring a grid system for attaching things to. Grids on electronics to allow air to move, either for cooling or for sound to pass through, are very much part of the historical aesthetic of electronics. Utilising the ventilation holes as a design space and aligning this with the holes required for attaching items to, became one of the first moments of realisation that there could be a standard based on the systems of 0.1” used in electronics.
- **Taking 0.1” for a walk** into the 3D space seemed an exciting place for combining nostalgia, designerly intent and craft. That there are a number of 2D options, as discussed earlier, that in similar ways allow for building out circuits in two dimensions, it felt like a missed opportunity not to have found ways to extend into 3D. Scaling 0.1” by a factor of two, seems the first place to start. In other words, take 1mm holes spaced at 0.1” as on bread/perf-board and making a grid of 0.1” holes spaced at 0.2”.
- **Optimising for single nozzle printers** to increase accessibility and interoperability between different printers. Like many 3D printer users, we have experienced setting a downloaded design printing and returning to a tangle of PLA on the print bed. Although STL files and PLA sizes have been standardised, the way in which printers print is highly variable. Whilst printers with multiple nozzles can print both the object and dissolvable support structures to allow for more complex prints, we wanted a system that was optimised for single nozzle, low-end, printers in order to make this system as widely accessible and applicable as possible.

With these points of inspiration and motivation as our guides we developed pegBits over two distinct stages of a research project (anonymised project name - research that explored the relationship between craft (as practice and ethos) and the development of connected devices). The initial idea emerged during the design of a tiny social network connecting three of the researchers together through a tiny social internet of connected cameras (hiCams). The second stage was a more deliberate extension of pegBits as a kit for physical prototyping with a Raspberry Pi 5.

3 Stage One: hiCams

hiCams are peer-to-peer internet connected cameras and screens that act as a platform to explore the health of our relationship with internet connected cameras. Each camera exists as a connected pair providing a one-to-one viewing experience (Figure 2) (Figure 3). Based on Raspberry Pi Zero, they send images to another paired camera/screen. The focus of this particular paper is not the design and use of hiCams, rather the development of pegBits, but we are giving a brief description of what hiCams are in order to set the context for how and why pegBits were first developed.

An aim of pegBits was to allow adaptation of the hiCams to add attachments to the back plate using commonly available standardised inserts and screws. M2.5 (i.e. screws with a 2.5mm diameter) were chosen as this is the commonly adopted standard by Adafruit and Pimoroni parts. It also meant that the screws could (just) pass through the 2.54mm holes (0.1”). The creation of a particular range of components provided the opportunity to attach devices both to established manufactured products (e.g. camera tripod stands, IKEA peg boards etc.) and to other more unusual, and less industrially standardised items with hooks, eyelets and other attachments.

Drawing from the range of practices within the team, we integrated both craft making and aesthetic into the hiCams using natural materials. This involved hand processes and bricolage to create bespoke and personalised versions. One outcome was the use of different objects to act as adjustable legs for the hiCams. Attachments were made specifically to hold chopsticks and tree branches and further pegBit attachments were designed to hold pencil sharpeners, which when used with pencils afforded different height legs by sharpening the pencils to reduce height. Other pegBits were designed to hold a halo of Lego flowers or real twigs as adornments around the hiCams. We were also able to use locally collected aluminium cans in a homemade smelting forge to sand-cast elements for an adjustable ‘trumpet’ stand on which multiple hiCams could be housed together. Many of these experiments were playful, humorous—and on occasion not terribly practical or stable. But this approach was taken to give a sense of experimentation and also agency to each of the team members. It was also to move the hiCams away from an established ‘product’ or ‘prototype’ aesthetic enabling us to explore other visual languages and traditions of making that may better align with and embody the aspirations for craft practitioners (particularly one that challenges the notion of craft only as a classroom activity, of the kind we commonly see in educational prototyping).

4 Stage Two: pegBits for Pi 5

Following the realisation that the backplate pegBits attachments for the hiCams led to a rich engagement with designerly and crafty activities, we wanted to make a system of building wholly based on pegBits. To explore this, we set out to design a system of parts for building a Raspberry Pi 5 enclosure that could also house a small HDMI screen and battery—effectively a Raspberry Pi mobile device (Figure 4). Inspired by the international standard for paper sizes, ISO 216 (which includes A4), and the Eames film Powers of Ten [4], we constrained our system to powers of two, where the “two” meant two pegBit holes. This meant we could have sheets of pegBits with dimensions that were drawn from powers of two (for example 2, 4, 8, 16 etc.) and that doubled in size (for example 16x32, 32x32). This aligned with our approach of retaining designerly constraints rather than creating an entirely blank canvas. We could have picked sizes that optimised the size of the prototype for being as close a fit to the Pi 5 as possible, but instead we optimised for exploring a potential standard in scaling, and to create an identifiable visual language and standard much like Lego and Meccano (Figure 5).

The first challenge in making a kit for a Pi, which we also intend to extend to Arduino and other prototyping systems, is that there is no standard for the distances between the mounting holes used

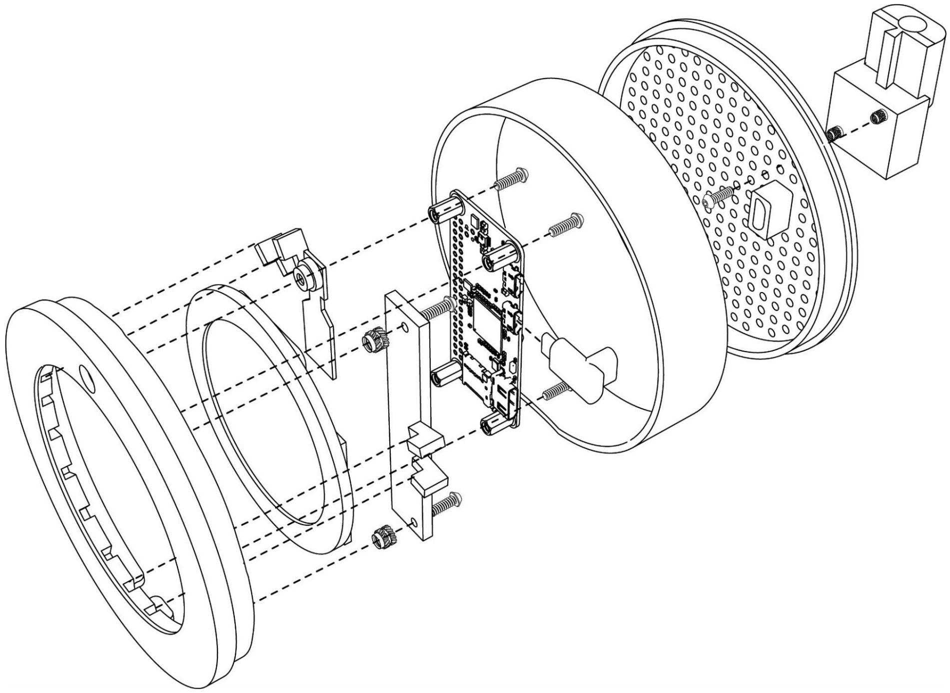

Figure 2: hiCam exploded view.

Figure 3: Various hiCam configurations

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to attach the boards to other surfaces and it does not align to the 0.1” spacing used by electronic components. The standards used for shields and hats on these platforms work only across their own ecosystem. This meant that we had to design adapters from the non-standard spacing of open hardware mounting holes into multiples of 0.1” used by pegBits.

Our intention for pegBits is that each piece is intuitive and easy to use. For example, when users pick up the adapter for a Pi it should be obvious how and where to attach it. We also found other clashes with standards. While there is a standard for screw threads (as mentioned earlier, we aligned with the commonly used M2.5) there is no commonly used outside diameter or depth for the brass inserts used to embed screwholes in plastic. This led to an extensive exploration of fasteners, eventually settling on a 3.5mm outside diameter. For all the threaded fixings in the adapters, and throughout the pegBit system we use threaded inserts. M2.5, 5mm long, heat pressed into the PLA. M2.5 is the emerging standard that seems to be adopted by AdaFruit, Pi-Hut and Pimoroni. To make sure they were aligned well, we mounted a soldering iron with an M2.5mm insert-specific solder tip in a drill press to give us constituent, repeatably accurate and vertical inserting of the threaded inserts. We also decided to keep the screws as accessible as possible. This meant it was easy to source for anyone and negated the need for specialist tools as much as possible.

5 Discussion

5.1 Designerly and Crafty

The interdisciplinary make-up of the team and the role of craft that we were exploring within the wider work in which pegBits sits resulted in activities that drew on both design and craft. Research exploring how digital design and making tools could be integrated into craft and designer maker practices (e.g. [2, 16]) sought to understand how the affordances of digital making could align with established craft oriented ways of thinking and making. The notion of ‘repeat and variation’ played a significant part. While industrial design (and manufacture) aspires to standardised repetition through mass production, craft has had a more flexible relationship with repetition. Repetition through making in batches and series is important to many craft practices, but equally significant is the recognition that variability is both built into the nature of the ‘handmade’ and important to craft’s value proposition (i.e. that all items are in some small way unique). There are ways in which digital tools can be put to work that can align with this craft-oriented approach to making. Repetition, as copy and paste, duplicate (or other similar functions) is a fundamental digital affordance, but similarly is the opportunity to make swift, but sensitive, edits and adjustments as designs iterate, allowing nuance and individuality into what can often be bland and anodyne digital outcomes.

Within the pegBits proposition we sought to support both mindsets and approaches. From a designerly perspective, through the constraints of the grid and the scaling in powers of two, the modularity of this system is founded in repetition. This allows users to build and reconfigure in a variety of ways with the confidence that things will always fit together. From a craft perspective, building in mechanisms (in the form of attachments) that invite and facilitate users to move away from the manufactured and the standardised, and to integrate more organic and the handmade aspects provides a different flavour of variation. Whilst the look and feel of the standardised aspects of pegBits appears to be very designerly, they are rooted in the idea of constant adaptability and change that is at the core of a craft approach to making and being. Moreover, they are based on engineering standards that were introduced into electronics over half a century ago to allow for repeatability and integration of integrated circuits. The combination of engineering, craft and design felt somewhat refreshing to us. We would argue that this pluralistic and inclusive approach embodies and can be seen as an ‘open platform’ approach.

5.2 Standardising Prototyping in Three Dimensions

It would be an understatement to say that breadboards have served us well: they are quite literally the foundations of electronic prototyping and development. But despite the prevalence of physical computing, it is surprising that the generalised systems for prototyping with electronics have remained in a stubbornly 2D form. We argue that we need to reframe our relationship with how electronics are prototyped to assume that 3D objects are being designed with circuit elements occupying the x, y and z axis. This has implications for the vertical stack with 3D emerging from 2D layering of circuits. For the purposes of debate, as we are not proposing here a solution, we are suggesting that it might be a good time for the TEI community to debate the relationship with electronics and the flat and stacked breadboard, perfboard, PCB. Could we, for example, have breadboards that are 3D without the wires falling out. Could spacers between boards contain right-(and other) angle forms?

Achieving this will require a degree of standardisation. It is a continuing point of frustration that there seems to be no agreed practice or standard of how mounting holes are placed on open hardware circuit boards that cross between ecosystems. Raspberry Pi’s approach to using the GPIO pins to centre mounting holes is one emerging standard, but the spacing between these is not aligned to multiples of 0.1”. They align across the Pi ecosystem, but not to a base-standard. Similar issues exist in the Arduino ecosystem. What we see in its place are hacks to join the systems and fill the gap left by a lack of standard, something the community have been doing since the beginning: A good example is a user on the Arduino forum suggesting that “using a grid of multiples of 8mm c/c, holders with LEGO stud compatible interface could be 3D printed” [21], an idea not so different from what we have been exploring in pegBits. Standards matter: it is almost 200 years since Joseph Whitworth invented the standard for screw threads, and in doing so opened the door from the scientific to the industrial revolution [11]. We argue that if we are to inclusively move towards the maker revolution that Fried, Anderson, Gershenfeld and others have called for, then we need to have standards in scaling the size of 3D circuits and systems that make the journey from bits to atoms with non-specialised, but designerly or crafty, ways.

As our contribution to this, we intend to eventually make pegBits available through a public repository. But contemplating this reveals tensions around the appropriate audience: the coder community (e.g. GitHub) and the 3D printing community (e.g. Thingiverse). This uncertainty, seems echoed in the wider maker community,

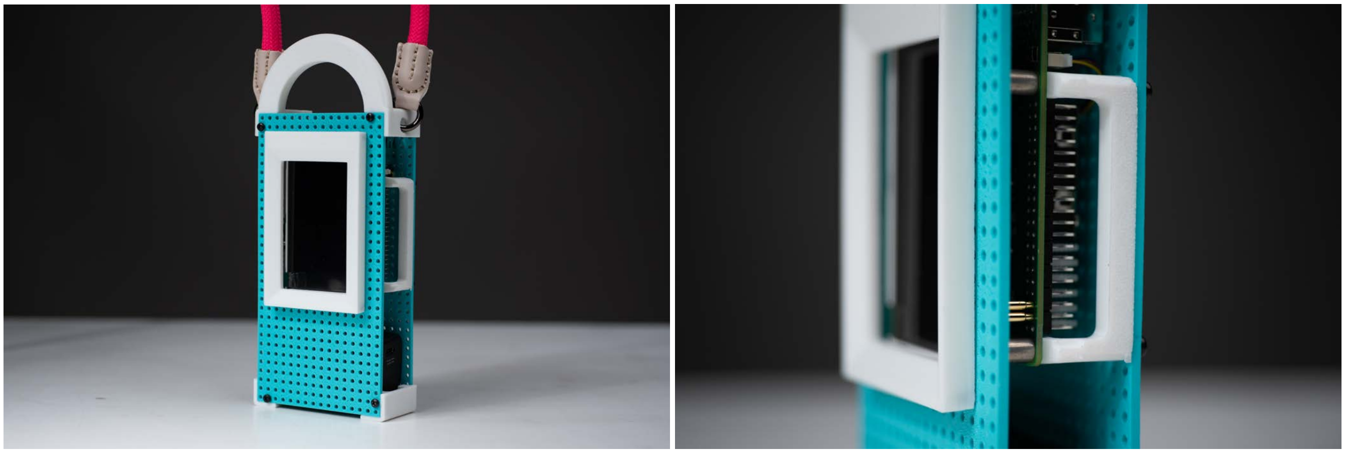

Figure 4: Raspberry Pi 5 mobile prototype.

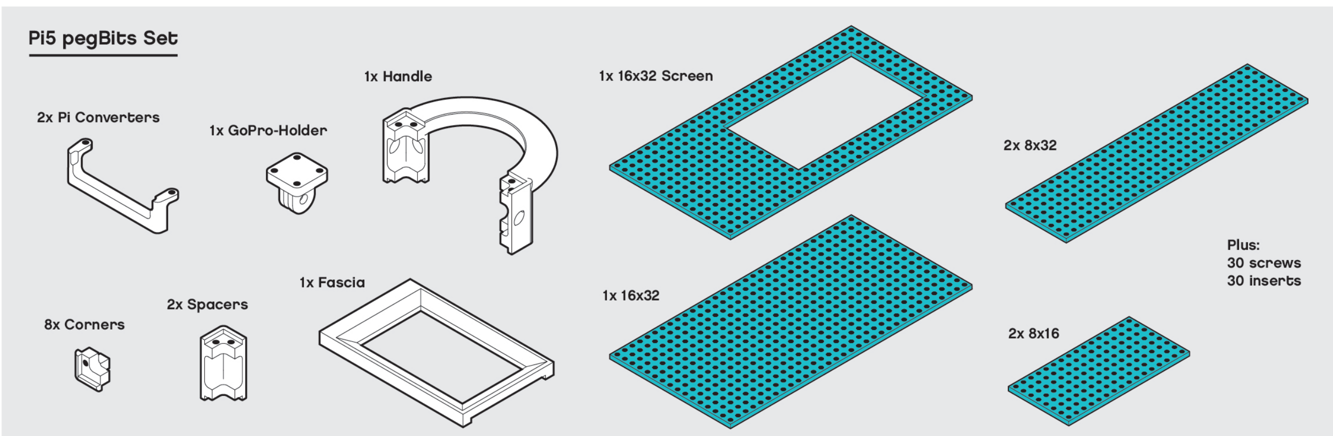

Figure 5: pegBits Pi5 mobile kit 1.

particularly in designerly and crafty approaches. Instructables, at one time thought to be the emerging place for sharing how to make things, have since become very mixed and hard to find. The lines of open are blurred, particularly with respect to commercialisation of the kind that we see with Thingiverse objects selling on Etsy. Thingiverse does not support the sharing of code (e.g. for Arduino or Raspberry Pi) and for this we use GitHub, but GitHub is not particularly well used and searchable for 3D printing files as well as code. Building a community to support physical prototyping will require us to resolve these tensions.

6 Conclusions

In this work in progress paper we have shown an early set of iterations on a 3D prototyping system that takes the 0.1" hole separation of Dual In Line chips and extends it to a construction system for building hybrid digitally-produced (e.g 3D printed) and crafted (e.g natural materials) research prototypes based on open hardware. In doing so, we realised that there was a wider discussion on physical and electronic standards not aligning well. We argue that for bits and atoms to be graspable by as many communities as possible that we need to revisit standards for 3D construction, design and crafting of physical housings for open hardware. We hope that this paper serves as creative provocation to these wider issues and also that the specific introduction to pegBits is useful as an achievable way of integrating electronics into the physical world in a way that affords adaptation and construction with a baked in building block standardisation and constraints.

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