# Domestic Widgets: Leveraging Household Creativity in Co-Creating Data Physicalisations

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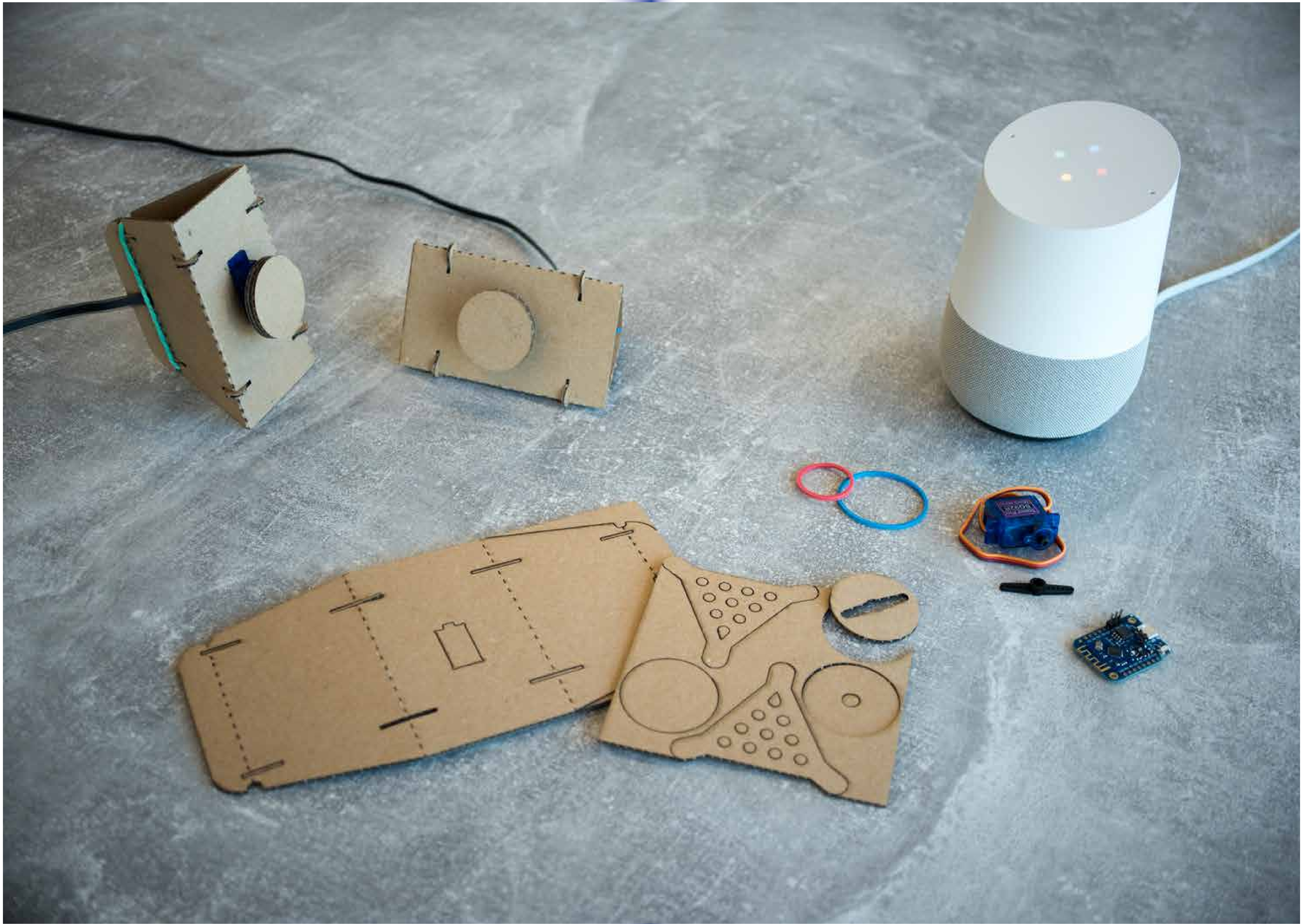
**Abstract:** The home environment is a complex design space, especially when it has multiple inhabitants. As such, the home presents challenges for the design of smart products. Householders may be different ages and have differing interests, needs, and attitudes towards technology. We pursued a research-through-design study with family households to envision and 'co-create' the future of data-enabled artifacts for their homes. We have iteratively developed domestic research artefacts for these households that are open, data-enabled, physical visualisations. These artefacts - called Domestic Widgets - are customisable in their design and functionality throughout their lifespan. The development process highlights design challenges for sustained co-creation and the leveraging of household creativity in (co-creation) research toolkits. These include the need to allow and inspire iterative customization, the need to accommodate changing roles within the home ecology, and the aim that such design should be inclusive for all family members (irrespective of age and technical proficiency), whilst maintaining a role and purpose in the home. We invite the RTD community to critically discuss our, and other, open and iterative end-user designs for sustained co-creation. By presenting unbuilt and interactive pre-built Domestic Widgets, we interactively foster engagement with practises of sustained co-creation.

**Keywords:** Internet of Things; Co-Creation; Physical Visualizations; Research Toolkit; Family; Research through Design



## Research Context

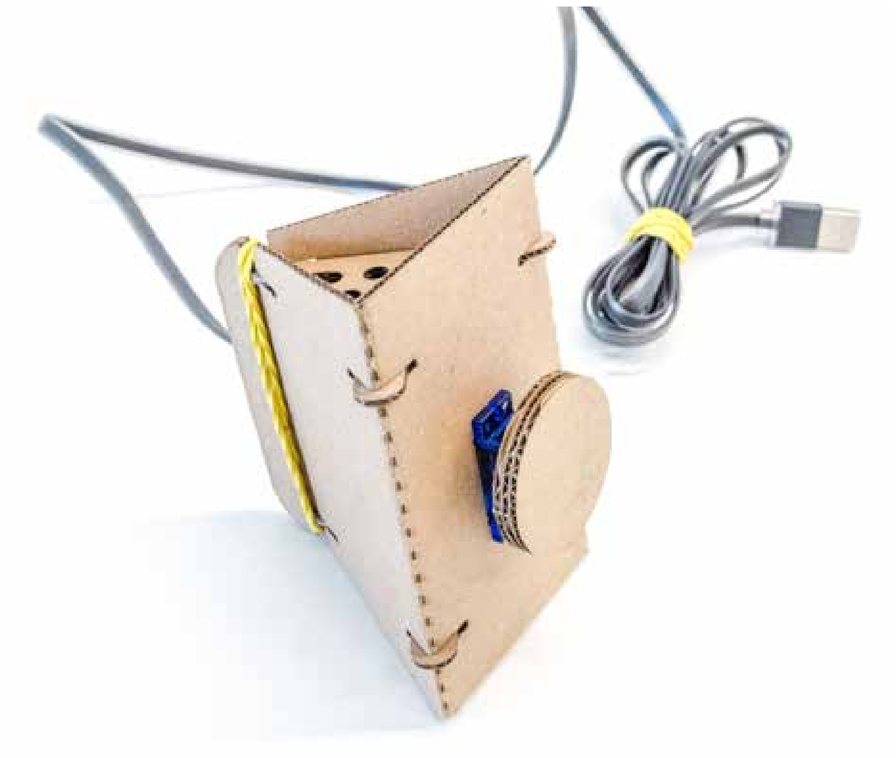
Programmable hardware and software allows us to build and experiment with computation in many professional and leisure activities. Developments in programmable hardware are often argued for because "current prototyping tools for electronics and programming are mostly targeted to engineering, robotics and technical audiences" (Barragán, 2004, p. 3). Efforts in exploring prototyping solutions have led to innumerable prototyping boards (e.g., Arduino, Raspberry PI) and programming languages. This has influenced manufacturing processes and product development processes; and these solutions are increasingly integrated into education to teach '21st-century skills', such as creativity, critical thinking and digital literacy.

The growth in supply and demand of these (commercially available) programming and hardware kits further incentivised the rise of the 'expert amateur' (Kuznetsov and Paulos, 2010), for whom participating in Do-It-Yourself (DIY) practises is not solely motivated by utility. An expanding demographic of users are being empowered to use electronics for - amongst other things - pleasure, utility and expressiveness (Tanenbaum et al., 2013). Here, the responsibilities of implementation that have traditionally been held by designers, programmers and developers increasingly shifts towards the user. In return, more design effort is focused on supportive infrastructure and standardised tools, materials and manufacturing processes. These should provide the user with a high flexibility in customisation and allow for user-led appropriation.

Empowering people to be creative is also a common goal in participatory research, including participatory design, co-creation and end-user development (EUD). Research-through-Design (RtD) approaches to co-creation, such as workshop formats, provide a collaborative context for engaging and supporting participants in creative practises with interactive technologies (e.g. sensors and actuators), enabling them to address potential obstacles in technology literacy or perceived creativity.

Many consumer market toolkits also aim to address these perceived obstacles by making hardware and software more accessible. Such toolkits are often used in educational settings and target younger users. Modular toolkits allow quick and easy tinkering with pre-made modules, either through physically connected modules such as LittleBits (https://littlebits.com/, last visited September 27, 2018), or wirelessly connected modules with flow- or block-based programming software such as SamLabs (https://uk.samlabs.com/, last visited September 27, 2018). Both of these toolkits lower the barriers to the creative exploration of electronics and coding, compared to platforms such as Arduino (https://www.arduino.cc/, last visited September 27, 2018) or Raspberry PI (https://www.raspberrypi.org/, last visited September 27, 2018). Platforms such as these often increase the difficulty in coding and using hardware, yet generally have a lower price point. This introduces a conflict between module-based toolkits that are priced higher than the typical costs for DIY projects (Kuznetsov and Paulos, 2010), with more affordable hardware platforms that require better programming and electronic skills. This remains a challenge for future consumer DIY hardware and software toolkits to lower both barriers.

A number of specially designed toolkits and systems have been developed by researchers in the participatory tradition, to explore the future of smart homes and the Internet of Things (IoT). For example, the Loaded Dice (Lefeuvre et al., 2017) supports the exploration of coupling inputs and outputs with pre-made computational dice, for design ideation with IoT. The RtD approach with Loaded Dice removes the need for end-user (software or hardware) development. Instead, it focuses on experimenting with actual and sensorial experiences in co-creative settings. With developments in customisable, appropriable and deployable toolkits and products, EUD research further aims to learn from the reflective development process of (professional) end-users - in-situ – that scaffolds in-depth research in context, such as on the subject of connectivity in (smart) homes. Tailored towards Tangible and Embodied Interfaces (TEI), Tetteroo and colleagues (Tetteroo et al., 2013) elaborate on five key challenges to achieve this aim, including, but not limited to, *supporting end-users in designing interactivity*, and *integrating the virtual with the physical*. Conducting participatory research in households strengthens these challenges, particularly as obstacles cannot always be mediated by human facilitators. Whilst the consumer market toolkits provide support for these to some extent, we still see a group of users not being involved in the DIY of 'smart' artefacts. This group might include householders who are demotivated by technical thresholds, or those who are just not that interested.



<Figure 2. An example of an assembled Domestic Widget. At this stage, the design of the moving visualisation is merely a 'blank' disc, and must be finished in order to visualise and give meaning to any chosen connected data. Each Widget is powered over USB, either through a USB charger or Power Bank. The latter provides more mobility, yet requires occasional maintenance.

Photo by authors

Whilst IoT is a new technological paradigm, hacking, making and similar familiar DIY practises at home have been around for many decades. One particular activity that is relatable to householders is tinkering and crafting with household materials. This activity is accessible to most, and performed by the younger ages both at home and at school. With such a continuous interest in this, and other types of household crafts (Kuznetsov and Paulos, 2010), we set out to develop a research toolkit to involve younger users in co-creating the future of IoT for smart homes. We iteratively designed a discovery-driven toolkit design that focuses on crafting with household materials - arguably the Research Product (Odom et al., 2016) of our research inquiry. The next chapter will present the design of the toolkit, after which we discuss considerations that arose during the development process. These include the prior mentioned challenges for EUD designs, and additional considerations for equivalent future DIY data-enabled toolkits.

## Domestic Widgets

Domestic Widgets are made from pre-perforated and pre-cut cardboard (Figure 1), with a flat-pack punch out and foldable enclosure accompanied by: a pre-programmed microcontroller (Wemos D1 Mini); a 2-meter thin and flexible USB cable; a popular 180-degree micro servo motor (SG90 or SG92R); a USB charger; and a rubber band or two. The components are basic enough in functionality to allow anyone to assemble a Domestic Widget (see Fig. 1 - 4). A Domestic Widget will move anything attached to its servo motor based on a configured data source, effectively acting as a data physicalisation (Jansen et al., 2015). These Widgets, upon providing power and an initial setup using a smartphone or laptop, are connected to the internet over Wi-Fi and ready to be configured using a smart speaker such as the Google Home (Mini), see Figure 6. In order to give meaning to any configured connectivity, the design requires additional form development by its end-users. Figure 5 demonstrates a subset of possibilities for how a Widget could be used and appropriated. The 'unfinished' Widget is symmetrically designed, resulting in a wedge-like form factor that can be positioned in multiple ways.

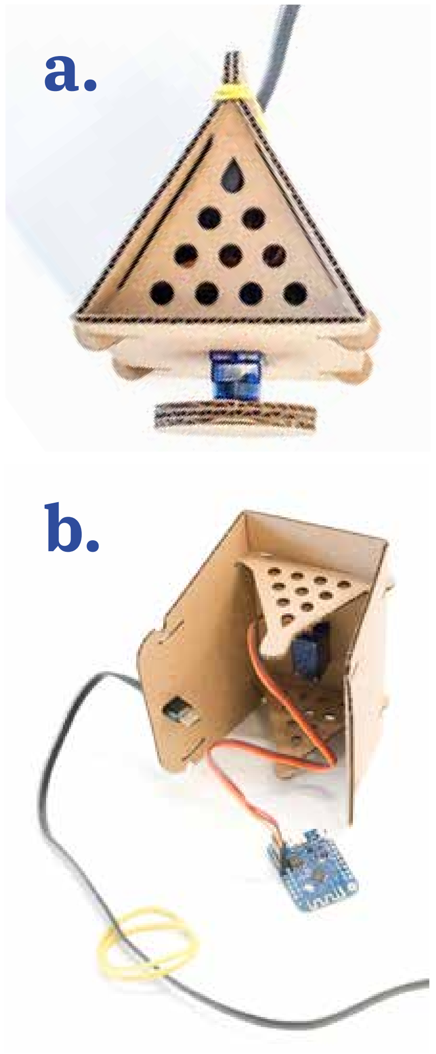
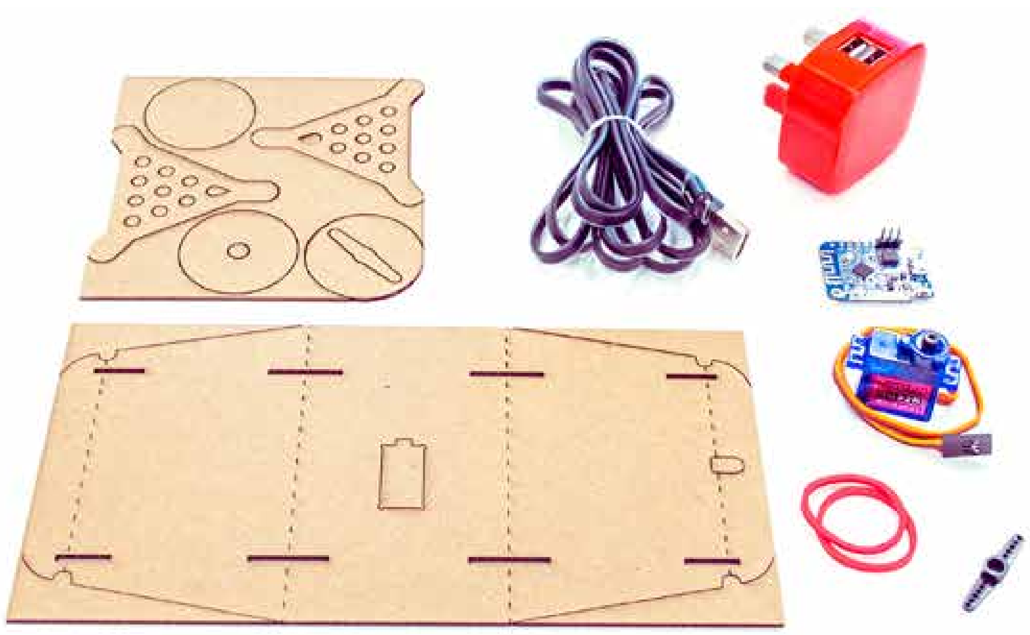
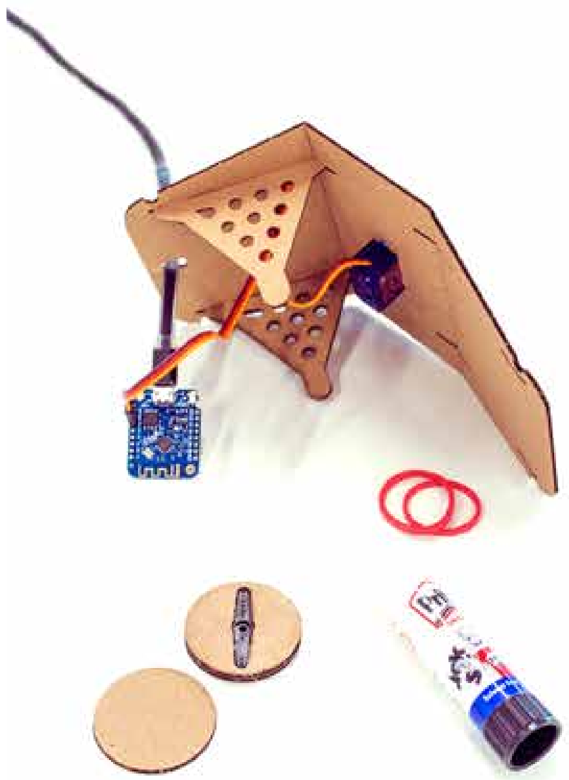



**Figure 3a, b.** Holes in the triangles allow for (microcontroller) heat and (servo motor) sound dissipation, and offer additional ways of attachment - for example for hooks, wires and threads. The USB cable is horizontally entered through the middle-back, such that an orientation is not suggested (contrasting when the cable would be attached to the bottom-back). Upon folding and closing a Widget, the cable will (automatically) be twisted vertically. This this prevents the components from being pulled out, and thereby eliminates the need for a fixture to hold the microcontroller. The microcontroller thereby lays loose within the enclosure.

Photos by authors





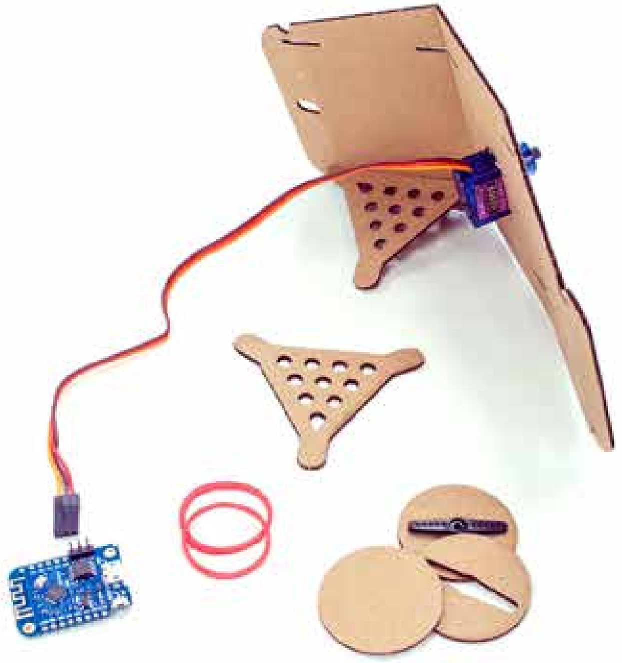


**Figure 4.** An environmentally friendly cardboard flat-pack toolkit design requires minimal tools and steps to assemble. Protruding triangular supports stick such that the assembly can be proceeded slowly and one step at a time. Solely the servo-arm assembly requires an adhesive, everything else remains detachable. All materials and components (top) can be acquired for less than $11, - for a single Widget.

Photo by authors


**Figure 5.** Examples of appropriation (by the authors) to demonstrate different possibilities of positioning and orientation. Whilst the circular cardboard servo-assembly flexibly allows for manipulation and attachment, further exploration should increase adaptability to increase the amount of possible uses.

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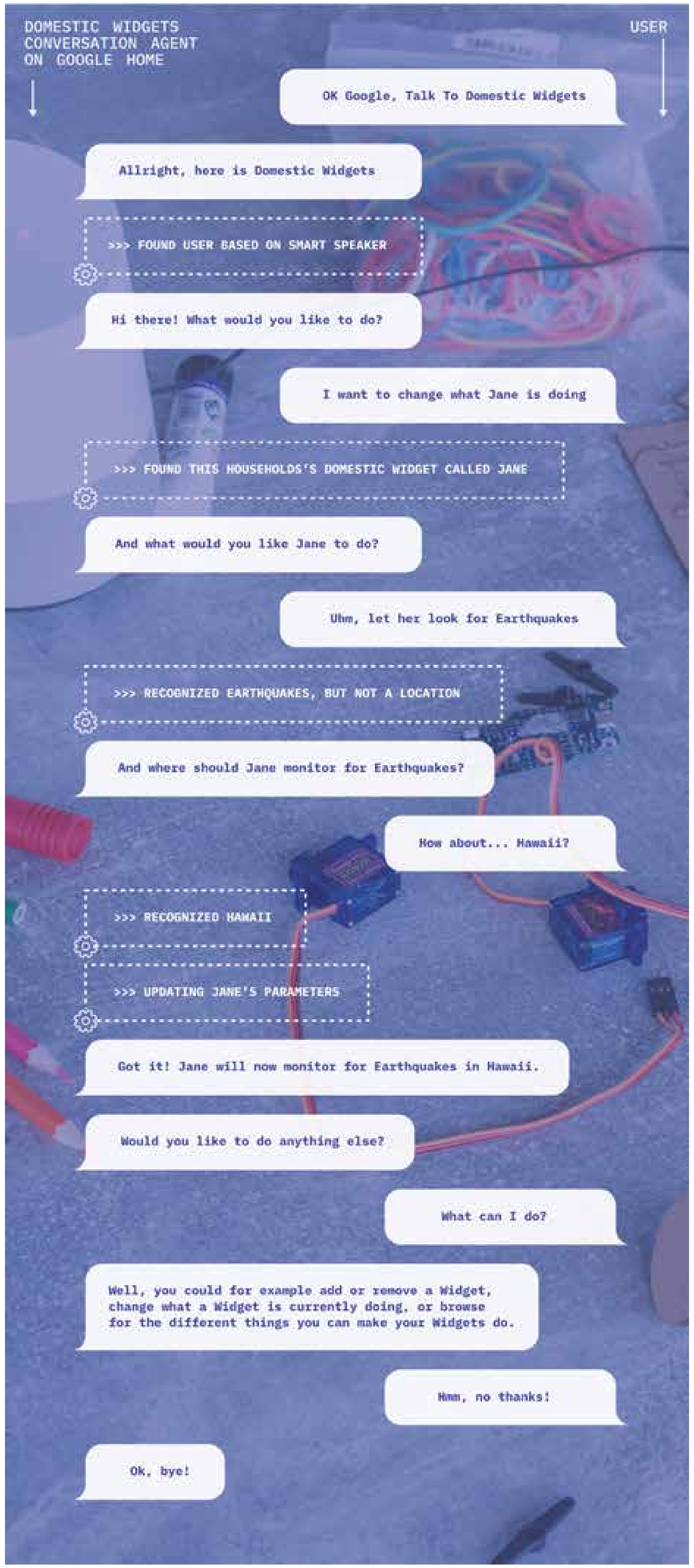


The seemingly aimless servo-motor attachment provides means for extension through adhesives and fasteners, yet does so without a clear intended end-result. Similarly, the non-decorated 'dull' cardboard prevents being suggestive about its positioning, which is why no printed cardboard (boxes) were recycled as construction material. In sum, the toolkit provides easy and accessible means to start making structurally sound personal physicalisations. It does so whilst being provided with minimal information about its intended use, so that this can be purposefully left open to interpretation by its users (Gaver et al., 2003). The toolkit thereby empowers families to tinker, craft and explore data-enabled artefacts with accessible materials and tools. This allows us, researchers, to investigate families' experiences of designing and developing equivalent connected systems.

## Data Physicalisations

In the era of increasingly connected everyday things, technology can promise people more control over how the things they own work together at home. But equally, these things are gaining more agency. In addition, more sources of data and intelligence are becoming available for everyday use - but, what benefits does this offer? The Domestic Widget design focuses on how we would integrate these developments in our family households, and how they would influence our routines and utility of these sources. To probe collaboration and discussion, we opted for our toolkit to focus on physicalisations, i.e. physical data visualisations (Jansen et al., 2015). Amongst a breadth of output modalities, movement's expressiveness affects multiple senses and is noticeable for multiple inhabitants at the same time. In light of crafting and DIY practises, physicality through movement further interacts with materials and objects in a way that visuals, temperature or sounds cannot. As such, we argue that creating physicalisations is an extremely useful DIY activity for engaging people in the discussion of digital connectivity in multi-person households - and we suggest similar projects could benefit equally from such an approach.

**Figure 6.** Example excerpt from a speech interaction with the Domestic Widgets conversation agent via the Google (Home) Assistant. Based on a predefined set of action possibilities by us, Google's machine-learning powered speech-to-text algorithm acts upon the user's input. It can thereby autonomously ask for additional input (e.g. 'where should Jane track the data?'), or forward the users intent to our custom cloud software. Each widget is required to be given a human name, so that both the system and users can refer to them via speech.

Image by authors

## Speech Interaction at Home

The audibility of speech-based interaction lowers the technical threshold for programming connected objects. It offers a high level of discoverability for inhabitants in the near vicinity, supporting legitimate peripheral participation and over the shoulder learning (Lave and Wenger, 1991). It furthermore democratises interaction (Porcheron et al., 2017), such that anyone is able and allowed to set a Widget's functionality. On the technical side, using a speech conversation agent enables the utilisation of smart speech recognition algorithms and appropriate prompts based on the users' inputs, even when the user input is not understood by the system. This provides an accessible way of programming (for designers and developers alike), whilst its output is comprehensible to act upon in further software. We chose speech-based interaction to be accessible and swift in making/crafting data-enabled artefacts - and argue similar work can further benefit from exploring voice-based interaction in the home.

## Towards Household Creativity

Our design process was inspired by Google's Paper Signals (https://papersignals.withgoogle.com/, last visited September 27, 2018), tiny paper-based data physicalisations for everyone to build themselves. We saw potential in the functionality and design of this product, which has a certain aesthetic that, even though it is self-built, remains an aesthetically pleasing (living) object. Furthermore, we build upon their speech-based interaction implementation, though completely revisited the physical and task design. In our own attempts to build these Signals, we quickly realised that the required coding, online authentication and time-consuming complex paper mechanics introduced a substantial threshold for ourselves and various user groups. These Signals are intended as a step-by-step instruction to achieve a pre-defined result. We wished to transfer the abilities and aesthetics of this project onto an open-ended design, with nearly no step-by-step instructions required. Whilst it is not uncommon to prepare or install designs on a participant-by-participant basis in RtD research, we additionally aimed to increase scalability and minimise researcher contact to further leave (more) participants in control.

To avoid influencing the materials or tools that users might be using in conjunction with our Toolkit, we focused our exploration on less-specialised tools and materials. These include printer paper, thick cardboard from boxes, or thinner cardboard from food supplies such as cereal boxes. Standard white paper (80 g/m2) did not offer enough structural support in creating simple self-supporting shapes (which was also the case for the Paper Signals project), whilst thicker paper is less likely to be present in many households. Thick cardboard is commonly available in households, but proved difficult to manipulate. We settled on thinner cardboard (~1,5 mm), which can be manipulated and is commonly found in homes. Experiments with this material looked aesthetically pleasing and retained its affordance that it may be cut, folded

**Figure 7.** Exploration in paper soon led to the use of cardboard. These displayed explorations aimed to establish a structural holder for the components, without specialized tools or templates. Further versions included an angled design to allow for externalisation of the servo assembly, and thereby varied (weighted) attachments.

Photos by authors

# Gauging Public Interest and Feedback at the Maker Faire

or ripped. With this material, we explored whether it was possible to make something from scratch. We found designing a structural base with simple tools extremely difficult. Additionally, the designs that could stand and hold the components (Figure 7) required detailed instructions to be easily replicated. This struggle resulted in abandoning the 'making from scratch' approach. Templates for end-users to cut out cardboard were deemed unfit, as they require the end-user to use specialised tools, such as craft knives or even digital fabrication methods. Our proposition was to design a foldable kit that can be prepared with specialised tools by us, but does not require these to be built at home. The resulting design (see Fig. 9) was presented, discussed and evaluated at the national Maker Faire.

## Maker Faire

In order to engage with our target group, we presented 20 working Domestic Widgets to a steady stream of DIY or technology savvy visitors (see Fig. 8). Using a tablet, visitors were able to configure each Widget through conversation. A children's activity (see Fig. 10 and 11b) aimed to encourage younger visitors at our stand to engage with the idea of connected artefacts. We provoked visitors to discuss the potential use of these Widgets, to evaluate their perceived usefulness, to imagine valuable data sources these Widgets could physicalise, and to gauge which aspects of such a toolkit would be interesting to families.

**Figure 8.** With an interim version of the Domestic Widgets we designed and displayed a stand at the national Maker Faire of 2018. This event - that focuses on families with members of all ages - allowed us to engage with potential end-users, and evaluate our design considerations for this diverse target group.

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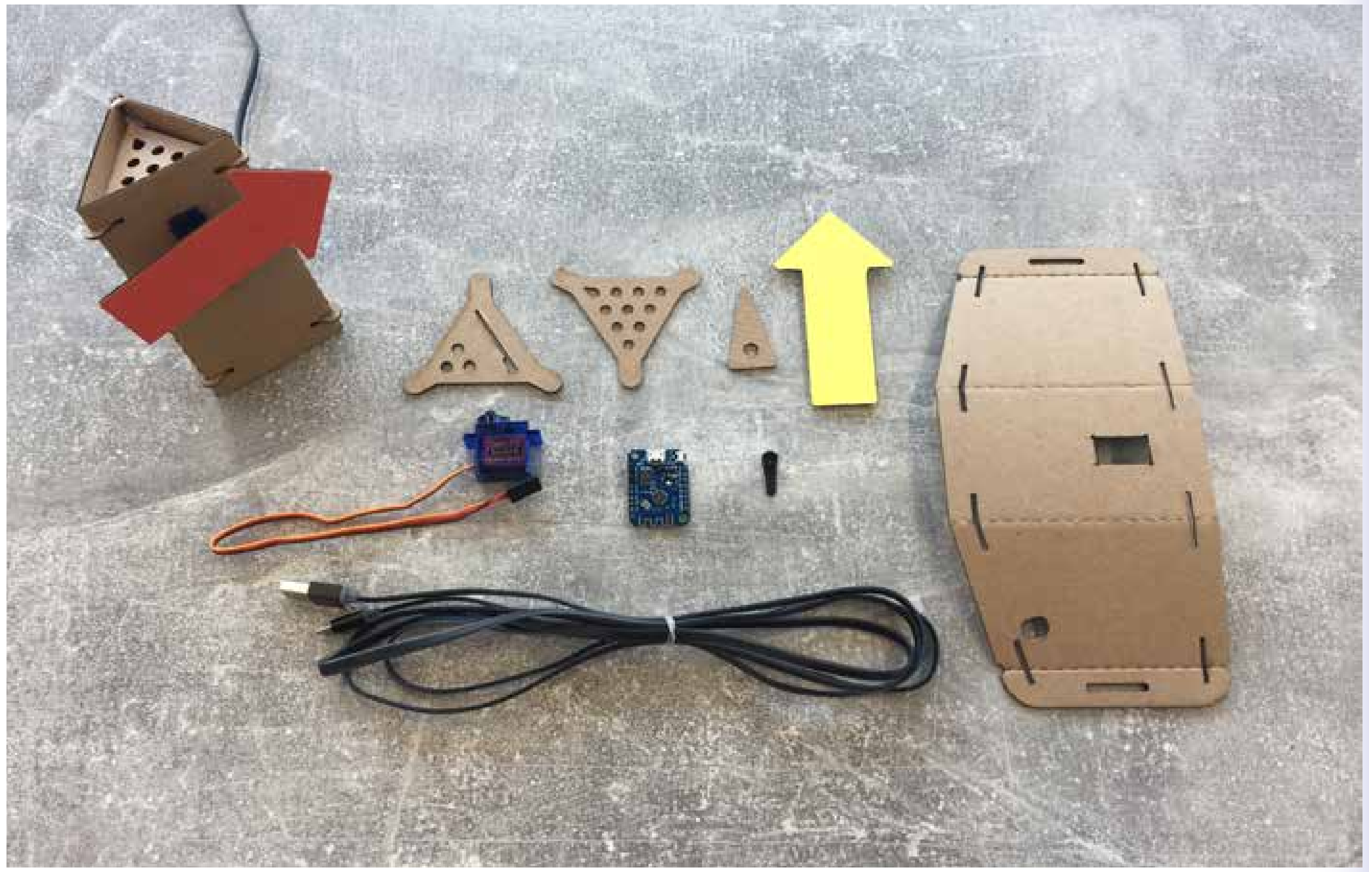

**Figure 9.** The interim version included similar components, yet differs from the final version in its form factor. The 'bottom' triangle includes a slot for the microcontroller, its USB cable enters the enclosure not in the middle-back, and the enclosure is non-symmetrical in the vertical axis. The servo-arm assembly was made as small as possible, which resulted in a triangular shape.

Photo by authors

Our stand piqued visitor interest in different ways (Fig. 8). Some visitors were eager to learn the inner-workings of a Domestic Widget, whilst others engaged in the configuration of one or multiple widgets. The popularity of the children's activity (Fig. 10 and 11b) further allowed us to engage them - and their parents - in a discussion on what a physical visualisation would or should mean for their household. When asked what data these widgets should physicalise (and when anything is possible), visitors suggested a wide variety of data sources, both generic data (e.g. the time in Bangkok) and personal data (e.g. the Wi-Fi bandwidth usage at home) alike. Suggestions included, but were not limited to, Widget functionality such that it represents things like the current wind direction, or when the next train will pass by, or the current room temperature, or the bandwidth used on the local network or a countdown timer. Suggestions that are more personally related data sources included, but were not limited to: a reminder to take some medicine, the emotional state of the cat in the house, where a family member currently is, or when a certain fashion item is on sale. In response to 'where' the visitors would place their Widget, suggestions ranged from the living room, to the kitchen, the office or simply any room.

The variety of Widget placements is currently covered by their wireless connectivity. The mix of envisioned useful data sources further reflects reported use of current data connectivity platforms such as IFTTT (Ur et al., 2016). Even though we successfully implemented a speech-based configuration of our Widgets, the types of accessible resources that we could offer users were limited (even in a research context) - particularly those which do not require authentication or screen-based input to successfully be configured. This holds especially true for the suggestions that are more related to personal events or activities. For example, one visitor suggested that pointing and clicking on a part of a webpage whilst browsing could result in a Widget tracking that part of the website. If we envision that this and

**Figure 10.** A 'mini' Widget consisted out of a scaled down Domestic Widget design, without the triangles. With a push-pin an arrow could be attached, representing the physicalization of (manual) data.

Photo by authors




**Figure 11 a, b.** At the Maker Faire, we presented our interim design as 20 working Widgets (a) and attached a generic arrow symbol to physicalize connected data sources. Using an Android tablet (rather than voice in such noisy environments) visitors were able to assign different data sources to different Widgets. By using human names (a), references (or instructions) to specific Widgets could be made. An additional children's activity (b) consisted out of folding and decorating a 'mini' Widget (see also Figure 10). This further motivated family engagement and proved to be of much interest to the younger visitors.to the younger visitors.

Photo by authors

the other personal data sources become available and possible to implement, all this information would need to be abstracted in position or movement for the Widget to be represented. Furthermore, these sources vary in type of data, such as continuous, relative and absolute 'values'. From a developer perspective, we could standardise these abstractions, and provide fixed abstractions. However, we identify the opportunity to also involve the households in this abstraction – as they are the users that need to 'make sense' of their chosen preferred data source. These results emphasise the persistent challenge of including all household members in a collaborative use and application of data in the home environment.

During the event, we were able to discuss connectivity for the home with most visitors, yet less so with those aged seven years or younger. At the same time, the children's activity was enjoyed by all ages. This demonstrated the value of our crafting and tinkering approach to inclusively engage all family members of all ages in a discussion on data enabled artefacts, and led us to further pursue our conceptual Domestic Widget design.

## Further Form Explorations

Reflection upon our interim Widget design (see Fig. 9) led to the further exploration of form and affordance. Here, we evaluated the aesthetics of possible form factors, and assessed their practicality/utility (see Fig 12 and 13). The resulting design (see Fig. 1) includes a backwards tilt that ensures stability when weighted objects are attached - something a rectangular box would not. A wider shape would assist in this stability, but this removes the difference between positioning a Widget straight up, or on its side, effectively reducing the possible uses and possibility for appropriation.

The use of faceplates was explored in response to Maker Faire visitors' questions (i.e. "How would you know what it means?") and suggestions (see Fig. 13). The interim design implemented arrows, yet their meaning without a visible mapping was not understood. As the faceplates allow users to swiftly draw or write a mapping behind the arrows, this accessory would increase its ease of use. However, the faceplates equally strongly suggest this particular use case. As we would like to see the data being externalised in more and different ways by its users, we removed this accessory from the final version.

Similarly, the servo-arm assembly in the interim version (see Fig. 9) was not symmetrical. Changing this to a circle increased the ambiguity in its use, further supporting our aim to increase the open-endedness of the design.

## Concluding - Domestic Widgets for RtD

Persistent goals throughout the development of the Domestic Widgets were to keep the number of components low, and to minimise the specialist tools required to build the toolkit. Contrasting the required laser-cutter for preparing the cardboard, the

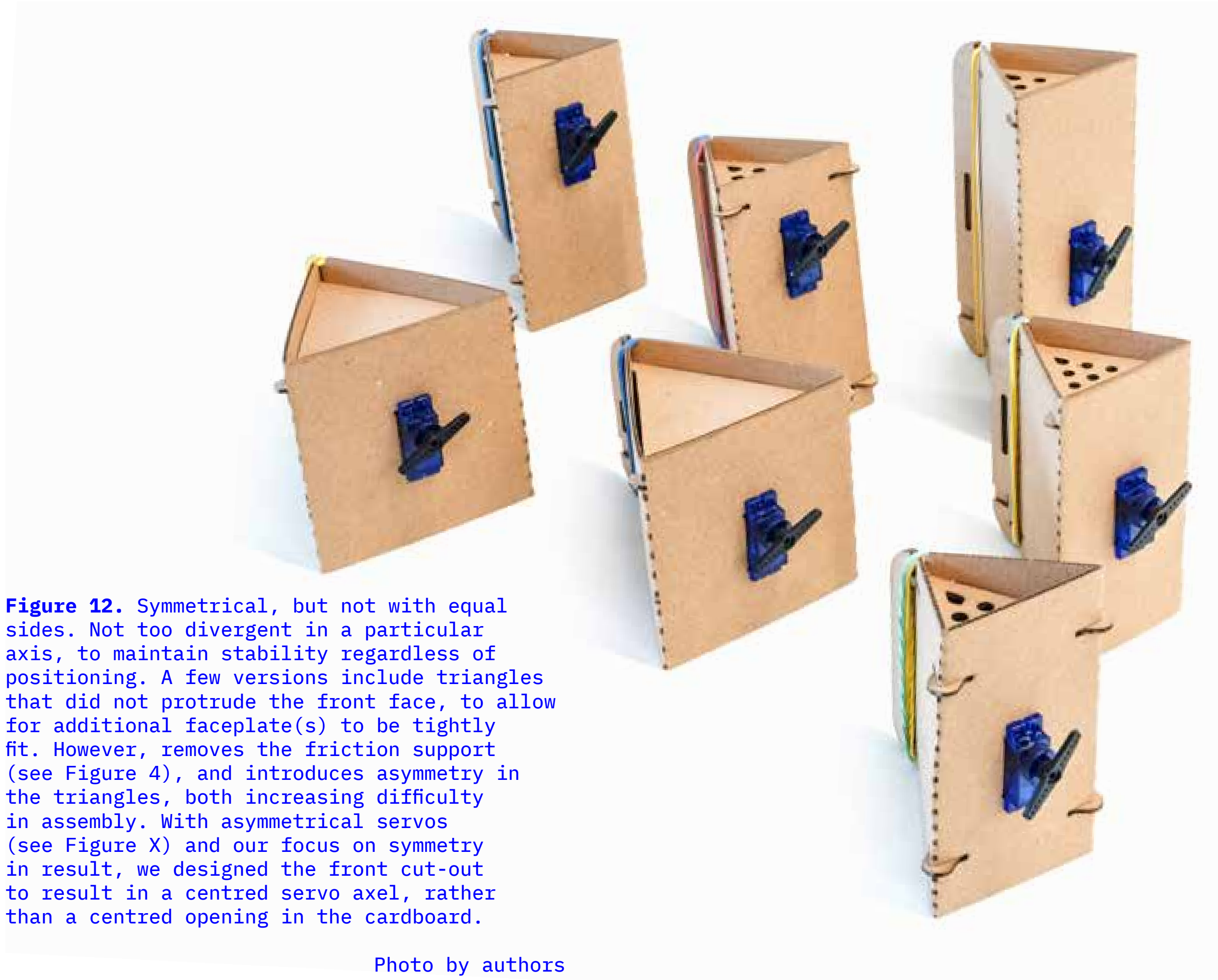

**Figure 12.** Symmetrical, but not with equal sides. Not too divergent in a particular axis, to maintain stability regardless of positioning. A few versions include triangles that did not protrude the front face, to allow for additional faceplate(s) to be tightly fit. However, removes the friction support (see Figure 4), and introduces asymmetry in the triangles, both increasing difficulty in assembly. With asymmetrical servos (see Figure X) and our focus on symmetry in result, we designed the front cut-out to result in a centred servo axel, rather than a centred opening in the cardboard.

Photo by authors

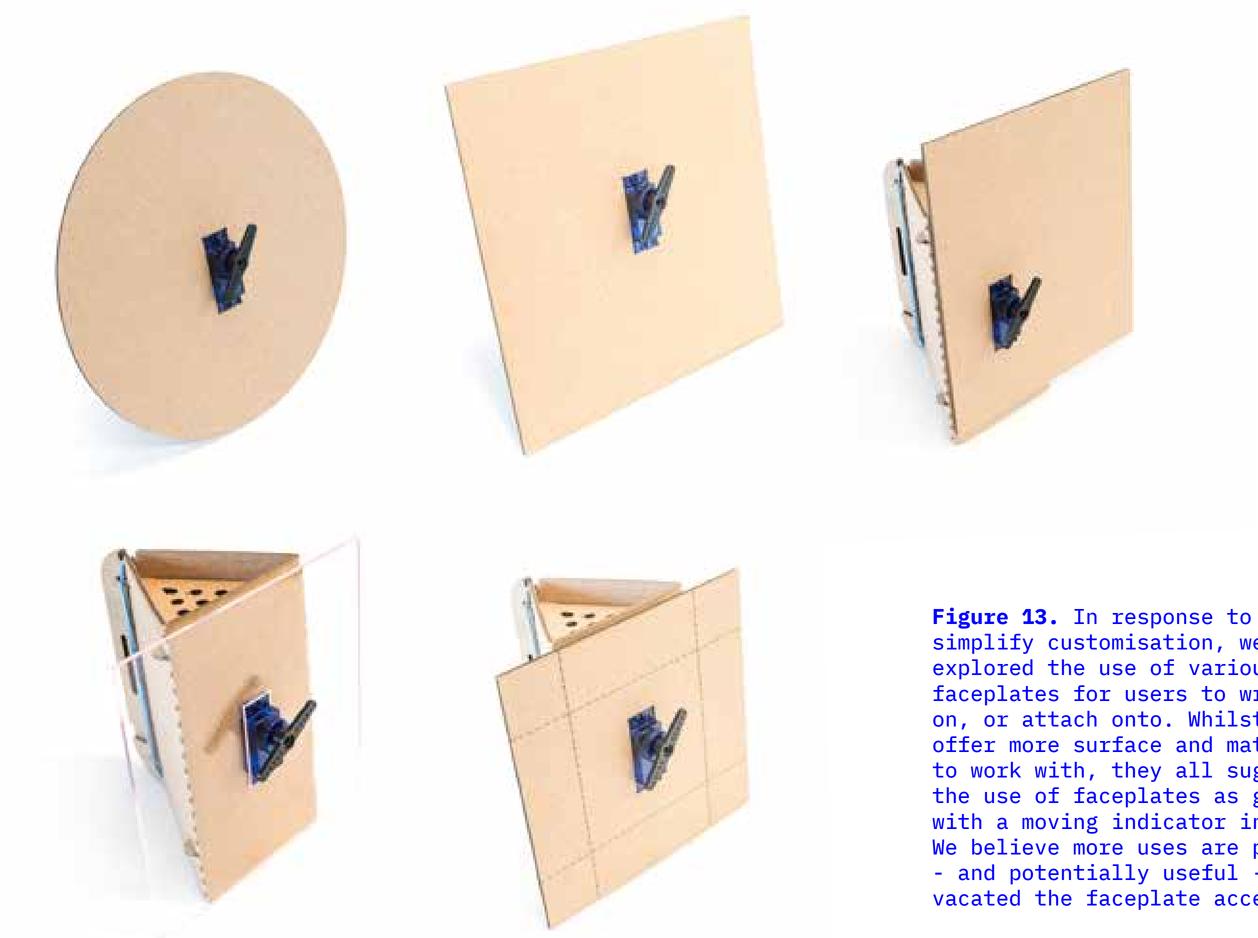

**Figure 13.** In response to simplify customisation, we explored the use of various faceplates for users to write on, or attach onto. Whilst these offer more surface and material to work with, they all suggest the use of faceplates as gauges with a moving indicator in front. We believe more uses are possible - and potentially useful - we vacated the faceplate accessory.

Photo by authors

current electrical components are readily available, and require minimal labour to assemble them into functional Widgets. In addition, with a total cost of less than €seven per Domestic Widget (excluding the USB power adapter), we believe this design is highly applicable and transferable to other practitioners and researchers.

Through the presentation of Domestic Widgets in this paper, we may argue that DIY and crafting offers a valuable, co-creative method for engaging discussions with end-users on future technology and its role in their lives. The participatory nature of our design might empower participating families as end-users to work through possible alternative (re-)configurations of data physicalisations at home. Yet, we seek broader and further explorations of various aspects that support this endeavour. For example, we still ponder about the balance between using generic accessible data sources or personal data sources that require additional (authentication) methods. Further, we wish to discuss the design in form and aesthetics such that it might motivate creative solutions more effectively. This includes the technical and mechanical elements (such as the attachments to the servo motor), but quite importantly it includes a design that sparks interest and motivates modification at first sight. With this, we will further improve participants ability to act upon their own creations (and reflections thereof). In turn, we can observe and study their reflective practises which can reveal needs and values for future smart domestic artefacts that might normally be too profound.

As is, our design elicits challenges and improvable design aspects. Even more so, we invite the RTD community to engage with us in discussion utilising craft, craft materials and speech-based interaction to establish sustained co-creation. Our IoT simplification into data physicalisations opens up re-configurations of their materiality, and thereby their appropriation and purpose in everyday scenarios.

To critically consider this approach, we engage the RTD community in hands-on building and tinkering with our Domestic Widgets, so that we might explore, evaluate and raise the next steps in these goals collaboratively. We additionally aim to do so through disseminating our work digitally: providing blueprints, tutorials (Desjardins et al., 2017), and potentially even by distributing our toolkits to like-minded researchers. At this stage of development, we are particularly interested in how the Domestic Widgets toolkit can leverage its material qualities, such that its material experience (Giaccardi and Karana, 2015) benefits families competences and values on a performative level to explore connected artefacts through making.

**Figure 14.** Through hands-on building and configuring Domestic Widgets, we can critically discuss the toolkits design and material influence on eliciting family values in RtD research.

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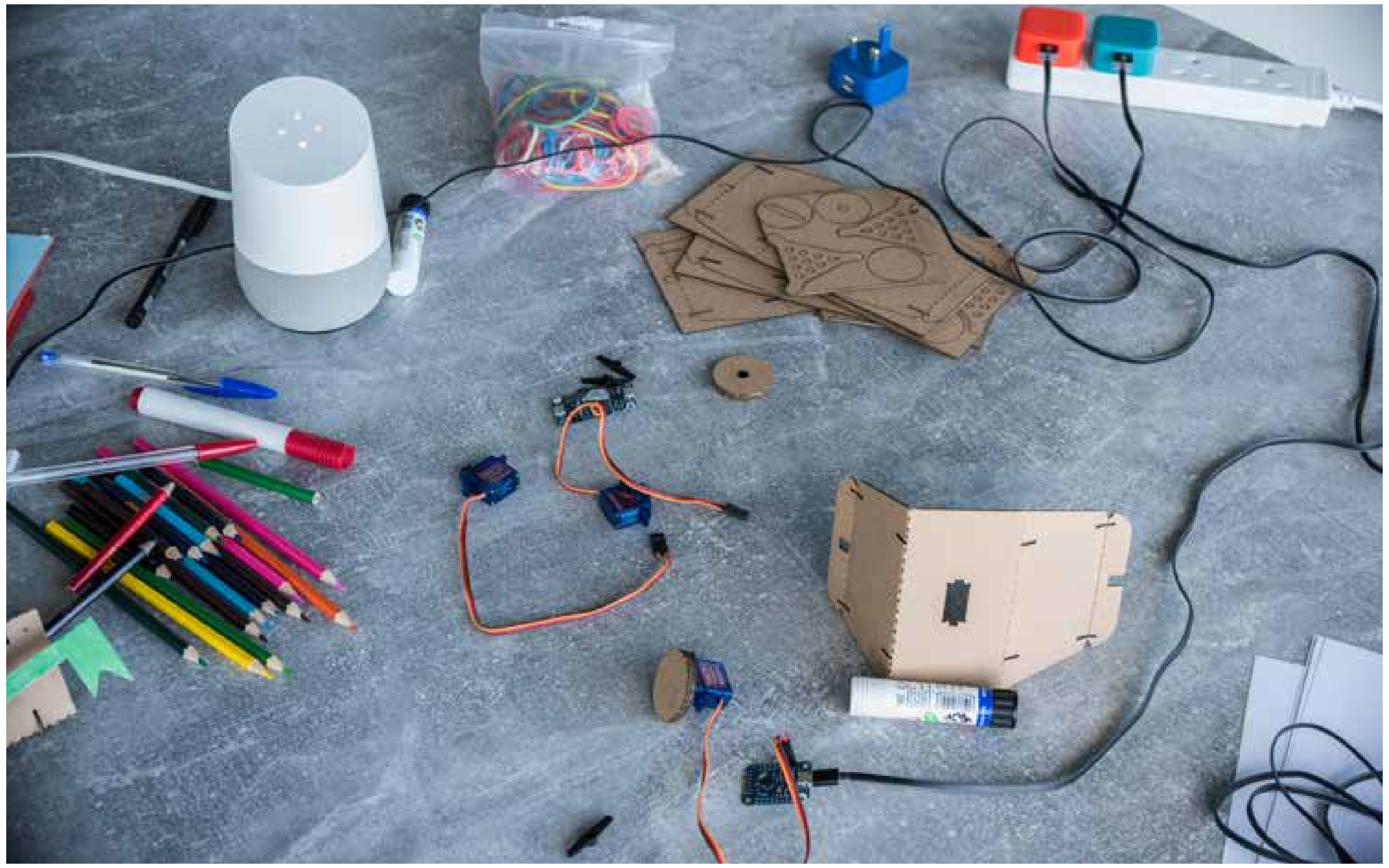

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