Designing with RFID

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ABSTRACT

Radio Frequency Identification (RFID) is a wireless technology that is emerging in consumer products as a method for input and interaction. Although RFID is relatively well known from a technical perspective, the methods for designing with RFID are less well understood, particularly the tangible and physical aspects of RFID form. Using a practice-driven design approach we explore the possibilities for richer design of RFID products in everyday contexts. Through sketching, making and form-explorations we build a visual and physical design vocabulary for RFID forms. This includes properties such as direction, balance, ergonomics and geometry that are communicated through design-focused language and visualisations.

Keywords

RFID, interaction design, industrial design, tangible interaction, applied design.

1. INTRODUCTION

With RFID technology being used in a wide range of activities, from daily interactions with transport to playful behaviour in toys, RFID products are becoming part of everyday life. The RFID tokens shown in Figure 1 are all used to access payment, ticketing and access control systems in various parts of the world. Products such as Tikitag (see product review below) show content-centric applications for RFID using tokens to access functions, media and content. In these products RFID may offer richer possibilities for interactions with everyday objects, particularly in enabling new kinds of tangible and object-based interactions in consumer products.

The forms that currently dominate the design of RFID products emerge from industrial and utilitarian contexts where the possibilities for RFID as designed products and methods for approaching these products are largely unexplored. RFID objects are largely limited to the most basic level of encapsulation and packaging where the physical RFID forms for these products are not being conceptualised or designed. In consequence many of the tangible and physical aspects of RFID interaction are being overlooked.

Figure 1. Collected RFID objects.

RFID is an abundant, inexpensive and flexible technology consisting of an antenna and a small amount of silicon memory (Figure 2A). At its simplest, when a passive RFID tag is in range of a powered reader it will communicate a small amount of data that indicates presence or identity. Because RFID is a wireless, radio-based technology it is inherently invisible once embedded, and this raises issues around visibility. How does the addition of hidden interactive qualities influence the design of these products? There is a need to develop tangible design qualities such as shape, materials, build quality and affordances.

Figure 2. Passive RFID technology from raw, unprotected circuitry through various protective encapsulations towards simple packaging.

In *Designing with RFID* we explore the potential for RFID products in everyday contexts through practice-driven design experiments. As interaction and industrial designers working with physical interactive products we are concerned with detailed interaction, form and materials. Drawing on practical design experiments with RFID and on tangible interaction research we conceptualise and design speculative RFID products and visualisations. Design methods include a product-review, sketching, form-explorations and prototyping with software, electronics hardware and physical making. In this process we explore ways in which RFID objects can be designed to balance various physical and digital qualities, guided by the ways in which these objects are used and experienced. This approach has illuminated opportunities and constraints in designing physical RFID objects that enriches the vocabulary around RFID for industrial and interaction designers where physical and visual material are essential elements.

We conclude with a beginnings of a design vocabulary for RFID objects that explores the range of qualities that may be put into use by designers, through a range of physical forms and visualisations. In this set of forms we see an emerging vocabulary around these ‘actionable’ qualities.

2. BACKGROUND

This research is set within the context of emerging technology and the ongoing discourse about ubiquitous computing and the "internet of things"[1] where digital artefacts, networks and interactions connect with physical products and environments. From a technical perspective the internet of things is a set of methods and standards, largely based on RFID[2], for tagging of objects in the physical world in order to connect them to digital networks. From a design perspective these technologies open up the possibility of looking at the relationship between the web and products in the physical world, where new opportunities for tangible interaction arise.

We draw on a history of research in tangible and ubiquitous computing where the potential 'bridging' of the digital and physical has been a central focus[3]. Much research in Tangible User Interfaces (or TUIs[4]) focuses on engineering and informatics perspectives[5] where emphasis is placed on rich and complex system interfaces[6]. Various approaches to RFID interaction include the 'touch-me paradigm' applied to children's games[7] where physical objects are used to construct simple interactions in games. Although they work in a similar domain, these approaches are concerned with the knowledge of RFID systems and technology and do not attempt to create detailed knowledge around the physical design of these interactions.

Figure 3. Mattel Hyperscan RFID game console.

Figure 4. Star Wars Commtech RFID action figure.

Figure 5. Brio Network RFID ‘e-mails’ and holder.

RFID offers many new material opportunities and constraints for designers. RFID tags can be embedded in just about anything, and being truly wireless, they don't require physical openings for network or power connections. But they are also limited in range, particularly around metal or water, and are susceptible to being broken and damaged by physical movement, temperature and moisture. Thus most RFID tags include extra stabilising material in order to protect the antenna and circuitry. The materials used must be opaque to radio signals, so plastics and paper are used (figure 2 B), but metals, liquids and other conductive materials inhibit their radio properties. Basic protective packaging includes paper (figure 2 C) and plastic lamination (figure 2 D), stickers and various other plastic enclosures (figure 2 E-L). The bare RFID tag itself does not offer significant meaning beyond its technical appearance. In order to create meaningful relationships towards these objects, RFID tags must be embedded in an object or signified by shape or sign (figure 2 J-L).

As RFID technologies move into everyday consumer products[8] they enable our design research efforts to move beyond technical implementations towards *methods for designing* as well as *patterns* or *platforms* that address the needs and concerns of industrial and interaction designers.

Through a focused exploration of the physical design implications of RFID-based products, physical form is emphasised to underlie its importance as part of interaction design. An activity of fabrication combines industrial design and interaction design in order to prototype and evaluate. The process has also focused on aesthetics in order to communicate the findings.

3. PRODUCT REVIEW

To understand the ways that RFID tags have been designed into consumer products, we conducted an extensive product review that documents many RFID products from around the world. This has been a process of reflection on existing industrial and consumer products[9].

3.1 Payment, transport and access control

RFID is most commonly used by consumers for ticketing, payments and access control. The design challenges in these contexts has concentrated on infrastructures and systems as opposed to the design of physical tokens. The design of these objects is limited to simple, mostly flat enclosures; cards, key-fobs or stickers as in Figure 1.

These objects rarely go beyond the basic forms of the protective encapsulations of the technology. For example the Oyster card in figure 1 (which enables ticketing on public transport in London with a single swipe of the card across a reader) is an encapsulation that has a 'wallet storage' characteristic equivalent to a credit card. An RFID keyfob (that might act as a key to access a building, see figure 2 H) is an encapsulation that enables hanging. In these utilitarian contexts, cheap objects need to be produced in the millions, with the potential for branding and simple customisation.

Figure 6. Tikitag USB RFID reader and stickers.

3.2 RFID in toys

Toys and playful consumer products have been one of the most interesting areas where RFID technology is being used. One of the first RFID-based toys – created by Hasbro in 1999 – was the 'Star Wars Commtech' range of action figures (see figure 4). This consisted of a Star Wars action figure with an RFID tag embedded in its stand, alongside an RFID reading device that played back sounds. The Commtech reader 'speaks' pre-recorded quotes from the Star Wars films, when figures are placed on its reading area.

More recent products include the Mattel Hyperscan games console shown in Figure 3 where parts of the game-play are controlled by a set of collectable RFID game cards. The Brio Network (see figure 5) has the theme of digital technology and uses plastic tokens that are a physical representation of digital networks. The Brio Smart-track embeds RFIDs in passive rail tracks that trigger different responses from a powered train which contains an RFID reader. The train responds to bridges, garages, stations, etc. based on the tags embedded within the rails below.

In many of these products the RFID tags are seen as collectable objects, almost like trading cards in the case of Hyperscan and the 'Dog-tag' features of the Commtech system. The Brio and Star Wars tags both make use of transparent packaging, where the exposed antenna and circuitry of an RFID tag is visible and reveals its 'technical' appearance. This technology-driven approach is interesting as it shows that the technology itself is perhaps the most fascinating aspect for many first-time users.

These toys do not go beyond the simplest tag-to-reader interactions, and rely on simply bringing two objects close together to create a resulting digital event. The technical properties of RFID, such as the batteryless tags which allow for cheap and maintenance free operation are perhaps the most significant opportunity for playful products and toys for children. But the physical design is limited to the form factors of the protective encapsulation of the tag.

3.3 RFID Peripherals

One of the most prominent current directions for RFID in consumer products is in simple RFID peripherals connected to personal computers. These RFID readers are connected with a simple USB connection, and allow physical objects to have a role in the interactions with digital desktop or the web. Placing an object on the reader will trigger an action on a personal computer.

The Nabaztag/tag is a plastic rabbit made by Violet that has a connection to the internet. The rabbit's nose is an RFID reader and when RFID-enabled objects are 'sniffed', it will respond with light, colour, movement or sound. The Tikitag (see Figure 6) and Violet Mir:ror[10] are attempts to offer physical object-based web applications for consumers where web pages or sound files can be loaded by the touch of an RFID tag. Both products are designed to encourage objects to be picked up and placed on a flat surface.

In the near future these peripherals are likely to enable the growth of content-centric applications that use RFID to connect various forms of media to physical objects, often referred to as token-based interaction[11]. The physical design of these peripherals involves flat plastic readers and basic RFID stickers, clearly and the extended possibilities of designing physical objects that work in everyday life is not being addressed in these products.

The design of current RFID objects remains at the simple level of encapsulation and packaging that does not yet address the wide range of physical possibilities for objects in everyday contexts.

Figure 7. The 'Bowl' interface and RFID objects.

The potential for RFID in consumer products is significant, given the inexpensive hardware of RFID systems and the opportunity to enable digital interactions with even the simplest of objects.

4. DESIGN EXPERIMENTS

The product review shows many uses for RFID but limited exploration of design qualities such as materials, shape, size, construction, manufacture, build quality and affordance.

We have taken a practice-driven design approach that focuses on form and expression rather than specific applications or technical infrastructures. The design explorations have been largely made in the context of the 'Bowl' prototype (See figure 7) where an RFID-reading prototype was installed for long-term evaluation in a domestic context[12]. Here physical objects triggered various digital media such as video, audio and photographs on a TV screen situated in a living room.

We used an explorative design approach to the physical aspects of RFID and this involved a process of prototyping, where physical RFID objects were built and evaluated in the 'Bowl' environment. Through a sketching process we developed an understanding of the relationships between physical forms and tags. Form-explorations were then used to visualise findings, to generate further models and to examine surface qualities.

Figure 8. Stitching RFID tag inside toy mouse.

The experiments were carried out and evaluated by a group of designers with diverse design skills: including model making, software programming, electronics hardware and digital 3D design. Subsequent iterations were informed by design evaluation and through teaching at a Master's level in interaction and industrial design.

4.1 Retro-fitting

Retrofitting is a convenient additive process that is common in RFID-based research projects[13]. By 'retro-fitting' we mean various methods for attaching, embedding or otherwise connecting tags to objects. We see examples of this in projects like the Mediamatic Symbolic Table[14] and in example projects made for Tikitag. This process shows design methods for attaching an RFID tag to an object, but also reveals some of the ways in which objects inherently lend themselves to becoming RFID-enabled.

Retro-fitting is a guided process where the initial object defines much of the outcome. It is convenient for objects that through natural cavities or flat surfaces lend themselves well to this process; things like dolls, books, cards and action figures. But trying to retro-fit more complex objects shows the boundaries of this approach. Large objects reveal that the active tag area is too small relative to the object, and soft toys show where both durability and placement of the tag is problematic.

We have retro-fitted tags to objects in various ways; from crude improvisation to delicate crafting. The simplest way of fitting a RFID tag to an object is using a RFID sticker or by gluing the tag

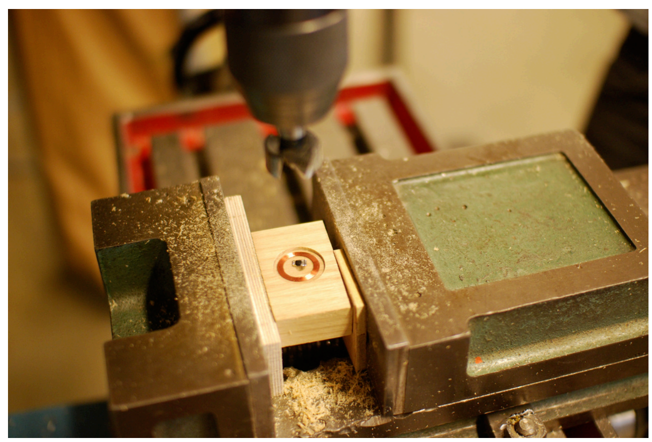

Figure 9. Machining tag into a block of birch.

Figure 10. Two RFID tags laminated between four sections of oak.

directly onto the object. More elaborate ways of retro-fitting includes embedding tags inside objects; stitching inside fabric, drilling holes or mechanically taking objects apart to place tags inside. Objects retro-fitted with tags gain improvised qualities such as the awkward placement of a tag or a visible tag area. As such this is a good method for uncovering possibilities but – by limiting possible objects and tag placement – it doesn't allow for more nuanced design considerations.

Hiding tags inside objects raises questions about visibility. How can embedded tags be signified by shape, material or sign? How might we use features of an object to guide the user towards the use of the tag. It also exposes the importance of developing design qualities such as shape, materials, build quality and affordances.

4.2 Embedding and object prototyping

Based on the retro-fitting experiments we designed discrete prototypes that address specific aspects of RFID and design issues such as materials, form and fabrication.

The intention was to refine the various characteristics of RFID objects through design prototyping and this extended process used industrial design methods of prototyping and fabrications as well as methods for form exploration. Part of our experiment focused on wood because of its malleable materiality and surface qualities that are rarely used in current RFID objects. Wood allowed us to make high-level prototypes at a 'professional' level rather than the crude improvisation of retro-fitting. This process used machining and lamination (see Figure 9) to embed tags into materials (see Figure 10). We also explored acrylic encapsulation and embedding tags in plastics.

Figure 12. A stick with with a tag embedded in the tip became a 'wand'.

The outcomes of this process is a set of rhetorical objects that display some directions for RFID. These objects are not designed as products but as artefacts that may provoke further discussion and investigation. In this set of objects we see an emerging form vocabulary that covers materials, form, shape, and size.

4.3 Sketching digital and physical qualities

In contrast to a more linear design approach, where sketching might be used as an initial exploratory tool to quickly generate ideas, here we use sketching as a way of understanding and evaluating the physical prototyping. We have focused on the relationships between the tags, the shapes and the behaviours. Sketching using different colours and line styles emphasises the integration between tags and objects, and aids in the understanding of the objects.

Sketching is used as an analytic tool, to evaluate, not just for idea generation. With black lines representing objects, red lines indicating tags and dashed lines for fields the possible 'touching'

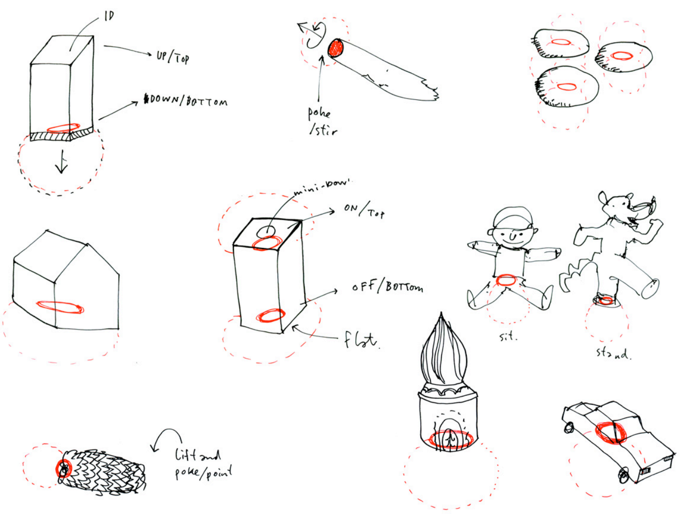

Figure 11. Sketching physical objects, RFID tags and radio fields using different line styles.

actions are explored (see figure 11). The ability to draw both the physical object and the invisible field of RFID is a powerful design tool for conceptualising new RFID interactions, particularly with objects that contain more than one tag.

4.4 Form explorations in 3D

Digital 3D modelling is a recent industrial design method that allows for rapid prototyping and iteration of shape, form and mechanics. Figure 13 is a visualisation of a selection of RFID objects in yellow that are surrounded by an approximation of an invisible RFID field in grey. The 'figure of 8' field shape was determined using a tag to map out the field profile of an RFID reader. These abstractions uncover some of the ways in which the

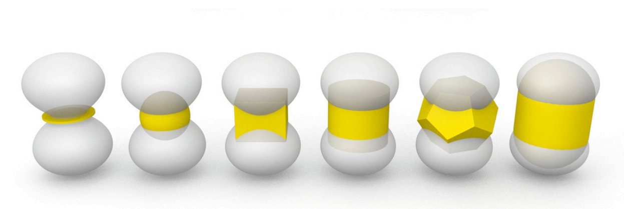

Figure 13. Abstractions of RFID fields and objects.

physical and the invisible RFID forms may interact to produce new touch gestures, where the physical form and the field profile interact in different ways. With the high quality of these visualisations they act as a way of lifting the findings out of rough sketching and experimenting stage and towards a generalisation of the research. They effectively communicate the physical aspects of the design findings and help us to evaluate and refine a vocabulary of forms.

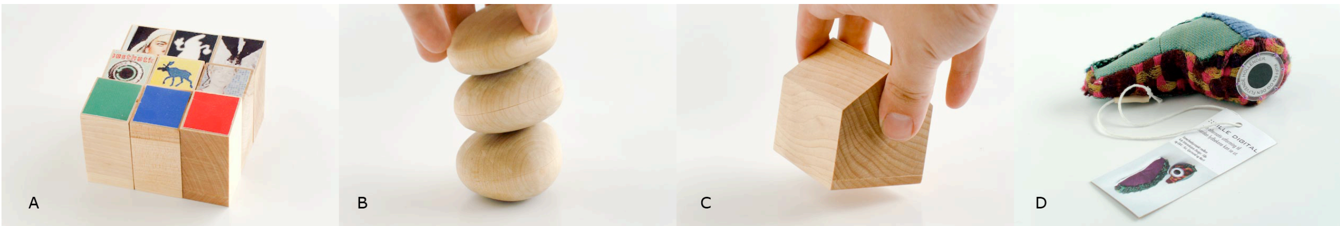

Figure 14. Designed RFID objects that experiment with A. similarity B. balance C. direction and D. ergonomics

5. DESIGN FINDINGS

The intention for this series of experiments was to gain a rich working knowledge of the kinds of design qualities that RFID objects may embody. This approach has illuminated opportunities and constraints in designing physical RFID objects that now need to be translated into patterns and models that are useful for interaction and industrial design.

Although a detailed analysis of affordance[15] is beyond the scope of this paper, no discussion of interaction with objects would be complete without drawing on these concepts. Norman[16] building on Gibson[17] defines affordances as "the perceived and actual properties of the object primarily those fundamental properties that determine how the object could possibly be used". But when making RFID objects – particularly in the context of retro-fitting where an object has existing associations – these affordances change through the merging of existing physical and new digital properties. This makes it a challenge to build new affordances specifically for RFID objects. We point towards some of the *fundamental properties that determine how RFID object could be used and designed.*

In industrial design the approaches to physical objects has included aesthetic taxonomies of form[18] that codify various elements and properties of primitives such as geometry, orientation, symmetry, spatial matrices, forces and relationships between forms as well as intention and expression. Through introducing RFID as an element into this approach, we begin to design an inspirational or generative set of forms for RFID-enabled objects.

Here we offer an analysis of the design findings and look towards the implications of the study. These findings are diverse and show the complexity of working with the design of physically interactive objects. The following section organises the findings into sets of associations and properties.

5.1 Literal associations

During the process of retro-fitting objects with RFID tags we uncovered a set of properties where the physical interactions were guided by existing associations offered by the object. In giving mundane everyday objects RFID abilities, we expose the existing associations that we have to those objects. Here the interactions and gestures that have been learned over time for such objects as *dolls, chesspieces, microphones, shower heads, telephones, flashlights, magnifying glasses, spraycans, screwdrivers, hammers, kitchen utensils, stamps*, and *handles* become important to consider.

Gestures like stirring, pointing, poking, drawing, shaking are influenced by learned association with existing objects. There are also multiple stages to these gestures such as 'grip and point' and 'pick and place'. Grip and point creates a 'wand' interaction, where a long object is pointed at a target. Pick and place creates interactions suitable for game-pieces, such as moving a chess piece.

In the case of characterful or anthropomorphic objects such as dolls and toys, the manipulation of the object involved sitting, or standing, which produced very specific interactions between object and reader. RFID has the possibility of reinforcing or amplifying these associations (such as a tag in the leg of a doll that supports an interaction when the doll stands) or disrupting them by introducing new uses that didn't exist in the original object. The retro-fitting process in particular has problems with breaking down the known affordances with existing objects, and supplementing them with new ones.

5.2 Elements of RFID form

Designing new gestures, taxonomies of form and affordances specifically for RFID will come only from designing a new set of objects, with their own elements and properties. Through the process of designing new RFID objects we uncovered properties such as direction, balance, similarity and geometry that address the qualities of RFID alongside physical form.

Direction

Direction is one of the strongest properties of RFID objects due to the two-sided nature of RFID fields (see figure 13). The RFID tag has longest range in two opposing directions, so objects that have two distinct sides such as a coin or card work well. More exploration led to concepts of flatness, up, down, top, bottom and ventured into multi-tagged objects (such as Figure 15 H) where one side was on and the other off. A cube has six sides and could potentially be used for six functions, and rectangular objects such as figure 15 E can be used to control two functions, on and off for instance.

Balance

Physical form may include structural or visual balance that has significance for RFID interaction. By being aligned or mis-aligned with the direction of the RFID field, balance can either reinforce or negate the strength of the RFID interactions. An experiment with wooden pebbles showed that objects with the ability to balance in two directions that align with the dominant direction of the RFID field create good interactions (see figure 14 B).

Ergonomics

Some objects such as the soft audiobook token in figure 14 D clearly had *handles* or *grips* that aided in the handling or grip related relative to the human hand. Objects such as the 'home' and 'albert' doll had very interesting handling qualities. Our aim in all objects was to provide for 'casual handling': objects that fit easily in the hand and are not unwieldy.

Similarity

We designed a set of similar objects that had subtle variations in form such as the 'Flickr' objects (See figure 14 A) that allow users

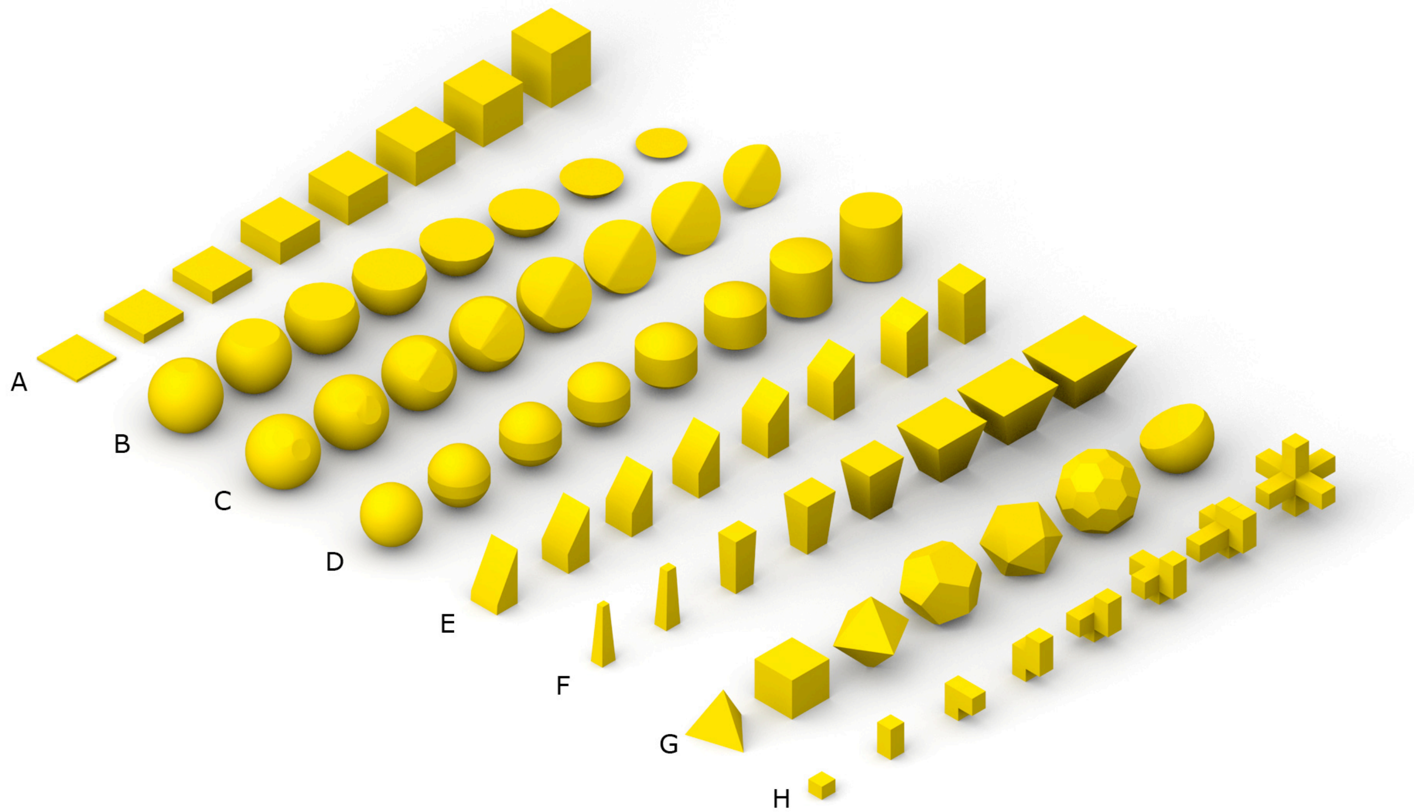

Figure 15. Digital 3D explorations of variations in physical RFID objects that include A-D. direction and F. balance.

to access Flickr slideshows. The design of similar sets of objects that have unique or customisable elements is clearly important for games and toys, but also perhaps in social media where objects representing unique identities are required. One example of this is the cuteness generator[19] that generates a set of visually similar but physically unique objects that mirror the unique identifiers stored on the RFID tag.

Geometry

The overall geometry of these objects has the function of suggesting directions for use such as *direction* and *grip*, but also in creating constraints such as a clear *up* and *down*. The cube for instance is difficult because it doesn't have clear direction or differentiation between sides, but may offer multiple functions in one object if fitted with multiple tags and signifiers such as graphics. The 'home' and 'Flickr' objects had subtle but clear direction and balance, indicated by a sloping top that indicated 'up'. Similarity between multiple objects encouraged exploration and use of more than one object at a time, and to engage in interactions where one object affected another.

In these experiments we see patterns for designing with RFID that do not only rely on learnt associations with existing objects, but explore new designed forms.

5.3 Visualisation

Digital 3D modelling allows rapid experimentation with multiple variations of form. By rendering some of the earlier findings from previous experiments using flat colours and photorealistic shading, we visualise some of the abstracted properties of RFID forms that can be used to conceptualise new RFID objects. Through variations in primitive geometry we are also able to further explore the elements of RFID form.

In figure 15 we see some of the variations and abstractions around actionable qualities of form. This is the beginning of a form vocabulary for RFID including balance (Figure 15 F), similarity, direction (Figure 15 B) and multi-direction (Figure 15 F-H).

The visual representation of these changing properties offers us the ability to reflect on the possibilities for building tangible objects that are used in RFID interactions, from the shift between a single function object to a multi-sided object in Figure 15 A to the subtle ways that an object can indicate its direction in Figure 15 D. The renderings are intended as communicative images that allow us and other designers to engage with, critique and make use of the opportunities in RFID form.

6. CONCLUSIONS

As the internet of things emerges as an increasingly important discourse within research and consumer products, the design of the RFID things themselves needs to be addressed. Our practice-driven approach involving products, models, objects and visualisations has resulted in a vision for an 'internet of things' that places designed things in the centre. By moving beyond an internet of stickers, credit cards and keyfobs the physical design of tangible interactions becomes of critical importance. Through these experiments we show some ways in which the internet of things may be made up of designed objects that fit daily practices such as leisure, play, entertainment, communication and lowthreshold interactions rather than just utilitarian or industrial applications.

A hands-on approach has allowed a re-evaluation of RFID technology through the lens of design, and communication of this in design-focused language. Through a process of making, evaluation and communicating a number of artefacts and an emergent design vocabulary is being built, that talks to the needs and concerns of interaction and industrial designers. This could be further extended into a rigourous taxonomy of RFID form and a deeper understanding of RFID as a material for design.

With an understanding of the potential richness of RFID in design, we start to see that the raw attributes of RFID tags like their inexpensiveness, directionality, adaptability and simplicity add up to a sum greater than the constituent parts. The qualities of RFID objects such as direction, grip, similarity and balance are all ways of interpreting this raw technology into actionable, design-able qualities. The sketching experiments also show that a detailed understanding of radio field profiles (such as those shown in figure 13) are an important direction for future research.

These making, sketching and visualisation processes may be important approaches for the applied design of emerging technologies in general. With the increasing implementation of networked and interactive technology in consumer electronics, critical aspects of digital and physical design will increasingly need to be addressed by both industrial and interaction designers. The design details are a critical part of the way in which these technologies are experienced, and by allowing design processes to guide the product development we are able to approach emerging technology in a plausible and understandable way.

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