ActuEating: Designing, Studying and Exploring Actuating Decorative Artefacts

Sara Nabil[1], Aluna Everitt[2], Miriam Sturdee[2], Jason Alexander[2], Simon Bowen[1], Peter Wright[1], David Kirk[3]

[1]Open Lab
Newcastle University
Newcastle upon Tyne, UK
{s.nabil-ahmed2, simon.bowen, p.c.wright}@ncl.ac.uk

[2]School of Computing & Communications
Lancaster University, UK
{a.everitt, m.sturdee, j.alexander}@lancaster.ac.uk

[3]Faculty of Engineering & Environment
Northumbria University
Newcastle upon Tyne, UK
david.kirk@northumbria.ac.uk

ABSTRACT

Actuating, dynamic materials offer substantial potential to enhance interior designs but there are currently few examples of how they might be utilised or impact user experiences. As part of a design-led exploration, we have prototyped (Wizard-of-Oz) an actuating, dining table runner (ActuEater1), and then developed a fully-interactive fabric version that both changes shape and colour (ActuEater2). Four in-situ deployments of 'ActuEaters' in different dinner settings and subsequent 'design crits' showed insights into how people perceive, interpret and interact with such slow-technology in interesting (and often unexpected) ways. The results of our 'ActuEating' studies provide evidence for how an actuating artefact can be simultaneously a resource for social engagement and an interactive decorative. In response, we explore design opportunities for situating novel interactive materials in everyday settings, taking the leap into a new generation of interactive spaces, and critically considering new aesthetic possibilities.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous.

Author Keywords

Shape-changing Interfaces; Organic User Interfaces; Interioraction; Multi-aesthetics; Colour-changing.

INTRODUCTION

Shape-changing interfaces (SCI) are physically, electronically, magnetically, pneumatically or mechanically capable of changing their shape as means of either input or output interaction with the user depending on shape-shifting materials or kinetic components that respond to different stimuli [5]. When situated within the built environment, SCI technology has the potential for many radically new diverse applications, e.g., dynamic artwork, shape-changing decoratives, pattern-changing fabrics, or even entire interactive interior spaces [35, 28]. Such notions of shape-changing dynamics have recently risen to prominence in both design and architecture literature. However, the 'artistic' and experiential aspects of SCI technology are rarely discussed and are thus identified as one of its main limitations [33]. Whilst many SCI explorations have focused heavily on the *development* of shape-changing materials and the *capabilities* of their interfaces, far fewer studies have considered the aesthetic value of the designs, overlooking how this might significantly influence user perception, engagement and ultimately, interaction, with such interfaces.

Figure 1. ActuEating: participants curiously exploring ActuEater2

Whilst interior decorative objects have significant potential to become dynamic, reactive and responsive, through the incorporation of Shape-Changing, Tangible and/or Organic User Interface [38] technologies [15, 23], there have, to-date, been relatively few examples of successful actuated decorative artefacts. One reason for this may be that such emerging technologies (although innovative) are struggling to find a place in our everyday environments (remaining mostly as curiosities within research labs). To help develop the conceptual design spaces from within which new and better technologies might emerge, a deeper grounded understanding needs to be developed of how people might perceive, interact with and otherwise experience such interfaces [33]. There are broad opportunities to

DIS '18, June 9–13, 2018, , Hong Kong

DOI: https://doi.org/10.1145/3196709.3196761

explore digital interfaces embedded within everyday artefacts, with the aim to make smart spaces more inhabitable, and interactive artefacts more adoptable. Such interactive artefacts should not be designed to appear 'technology-like' but could be designed and built to act like artefacts that people already admire, cherish and live with. This would extend the user experience in the built environment by adding a dynamic nature to interior design elements that match inhabitants' cultural expectations rather than appearing alien or ill-fitting. Taking shape-changing interfaces into an aesthetic design space opens up an opportunity for them to be incorporated into decorative artefacts, blending into our environments and supporting seamless transitions between physical and digital interactions.

The motivation behind our work is to 1) design exemplar interactive decorative artefacts and explore their potential, affordances, and limitations, 2) study how people interact with, interpret and experience an actuating piece of decorative fabric such as a table runner, and how it might change their experience of space and activity (in this case dining), and 3) discuss, from a user-centred perspective, possibilities and areas of future development for interactive spaces/materials.

In this paper, we present 'ActuEater1' and 'ActuEater2' as decorative centre-pieces on the dining table (see Figure 1). Utilising 'ambiguity' as a virtue [13] and 'slowness' as a value [31], our designs were created and then situated in-the-wild on four dining tables and subjected to post-study 'design crits' to drive the research forward. Our in-situ studies show how people perceive and interact idiosyncratically with a conventional decorative object that is 'actuating', yet concur when interpreting its interactions and discussing its impacts their dining experience. Furthermore, we present our reflections and discuss our main findings with regards to the overall experience of 'ActuEating' (social engagement in an interactive dining space) and the insights of people's sense-making of both ActuEaters. Furthermore, we present reflections on designing shape-changing interactive decorative artefacts.

The main contributions of this work are: 1) exploring the aesthetic design space of shape-changing interfaces in the form of decorative artefacts blending ubiquitously into our environments, rather than standing out as digital devices; 2) studying shape-change in a social event and how it affects people's experience in the space, and with each other; 3) exploring a broader interaction repertoire that is useful to learn how an SCI would be perceived and interacted with; and 4) studying how people learn and develop (individually and together) potential interactive scenarios with actuating objects.

RELATED WORK

Below we introduce some key considerations to help ground this work. Firstly, we discuss current efforts to develop shape-changing interior objects, then we discuss some aesthetic considerations of shape-changing materials before finally addressing the role of technology in supporting 'dining' experiences.

Shape-changing Interior Artefacts

Although there is some previous research around shape-changing actuation in furniture and interior objects, the work in this area is still somewhat limited. Examples of shape-changing interior objects in HCI research include the Earthquake Shelf [34], the colour-changing DigitalLace [36] and the Byobu room-divider [32]. Examples of shape-changing furniture include the colour-changing EmotoCouch [24], the shape-changing table/board [16] and coMotion [17], a horizontal shape-changing bench that changes its height and angle using 8 embedded linear actuator 'motors'. The study of coMotion gathered insights from 120 'unaware' members of the public who interacted with it (each for around 2mins). Although coMotion was remotely controlled by researchers i.e. Wizard of Oz (WoO), it enabled researchers to explore the users' interpretations, sense-making and experiences of its affordances and transitions. The pattern shape-changing (not form shape-changing), History Tablecloth [12] is a prominent example for a long-term study of situated interactive furniture. The 4-month study in a single 2-person household, provided a deeper insight into what it means to design artefacts in a real-world environment. Today still, as Gaver stated a decade ago, less purposeful, more exploratory and playful engagements that encourage people to explore, speculate and wonder, are poorly served by current technologies [12] and therefore still needs further research. Other examples of advanced shape-changing tabletops are Transform [22, 39], inForm [11] and PolySurface [9]. However, real-world applications that fit into our interior spaces are still quite limited.

Shape-changing Aesthetics

Visionary work on Radical Atoms [21] suggested that thoughtfully designed interfaces can and should be embodied in different materials and forms in our physical world. Inspired by this, some actuating interfaces were designed to explore people's experience with them and the sensational and emotional effects of such multi-aesthetic and deformable interfaces. For example, Textile Mirror [8], an actuated wall curtain, shows how interfaces can actively mirror and transform our feelings through traditional materials in our environments i.e. texture-changing fabrics can modify one's emotional state from stressed or angry to happy and calm. Similarly, Davis [7] explored a variety of different emotional expressions that can be communicated to users through texture-changing artefacts. Ueda [37] also explored actuated textiles through wrinkling shape-changing fabric as means of user interaction, and Bodanzky [2] has explored some of the potential expressive qualities of shape-changing surfaces and their actuating designs. Concepts such as Neuroaesthetics [7] and 'Aesthetic Interaction' [23] proposes how the aesthetics of visual and tactile interactivity can be used to activate not only visceral put perceptual senses, meanings and values and provoke self-reflective awareness through ubiquitous interaction with textural-changing interfaces. Proposed motivations for such interfaces include: being a conversation starter, material for storytelling, overcoming temporal blindness [6], entertainment and playfulness [26] and visualizing the unseen [28].

Interactive Eating Experiences

Previous HCI research has explored debatable ways in which digital technology should or could be used to change and/or enhance the eating experience [4, 20]. For example, in working with families, Ferdous [10] has attempted to transform the

disruptive experience of mobile phone use during family meals into a positive social experience, by utilizing phones as a form of collective engagement at the table. However, Hiniker [19] has studied the challenges of using mobile phones during family mealtimes and their implications on family members' social experience. Other work [14, 29] has considered the ways in which digital technology can help connect and engage lone diners geographically dispersed. Barden [1] explored the challenge of connecting distributed diners in a Telematic-Dinner-Party using cameras and projectors exploring augmented reality that blends into the physical world. Alternatively, Mitchell [25] designed a kinetic dining table that can synchronize the eating pace of dining companions to augment their social experience with mutual alignment. This work shows that such domestic and ritual activities can be prime settings for technological explorations, and point to the entanglement of technology with the aesthetic experiences of dining.

DESIGNING ACTUEATER1

Building on previous work, most notably coMotion [17], we wanted to explore SCIs as decorative artefacts, but embedded within complex social settings. Extending typical duration of user interaction to over an hour (instead of an average of 2mins) allows people the time to observe, practice, learn and develop a variety of interaction scenarios. A richer interaction repertoire can be designed using a wider range of different shape-changing physical actuations (than controlling one parameter/dimension) by controlling the location, scale, height and speed of a fine-grained grid of embedded actuators. For our first case study, we chose ShapeClips [18] to create a rapid working prototype. ShapeClips are prototyping toolkits for creating interactive shape-changing displays using vertical actuators (stepper-motors) animated with photo-sensors using any monitor.

Making

Inspired by PolySurface [9], we re-purposed the ShapeClips to build a dynamic and customizable shape-changing prototype that fits on a dining table as a traditional table runner. As ShapeClips vary between 8 and 18 cm in height, we embedded them within the table itself to ensure an initially flat surface on our table. After the software was re-programmed and the hardware electronic components were re-structured in the desired arrangements, a full-length table runner was made as ActuEater1 (see Figure 2). Similar to PolySurface [9], we designed ActuEater1 from stretchable Spandex fabric and a uniform custom-designed pattern laser-cut on 0.8 mm thin polypropylene sheets to give it a controlled semi-flexible moving capability. After fixing it together, we lined the edges with a satin golden-beige ribbon as a finishing touch to give it an original look and an aesthetic value similar to contemporary table runners. The final runner was 93×35 cm consisting of 10 ShapeClips in a 2×5 grid to control its inner body.

Actuations

Driven using a remote WoO interface, ActuEater1 could change its shape on top of the dining table in an array of different actuations: 1) Default state (sleep mode); 2) Located actuation (using a single bit in front of a certain diner) that either moves upwards and stays for a while or vibrates up and down slowly or rapidly; 3) Two located actuations (two bits away from each other interacting with users on both sides of the table); 4) Sequential deformation from one end to the other; 5) An animated wave motion moving across the table runner; 6) All-up and all-down. Height and speed are both controlled variables that allow variation in the resulting actuation. During testing we realized that when ActuEater returns to default state, it does not become flat, but leaves 'history wrinkles' i.e. traces of previous actuations, in the form of fabric bends. Although these traces were not intentional, it was an unexpected yet interesting feature of ActuEater1, showing a 'history' of actuation which we saw as an interaction richness rather than irregular performance.

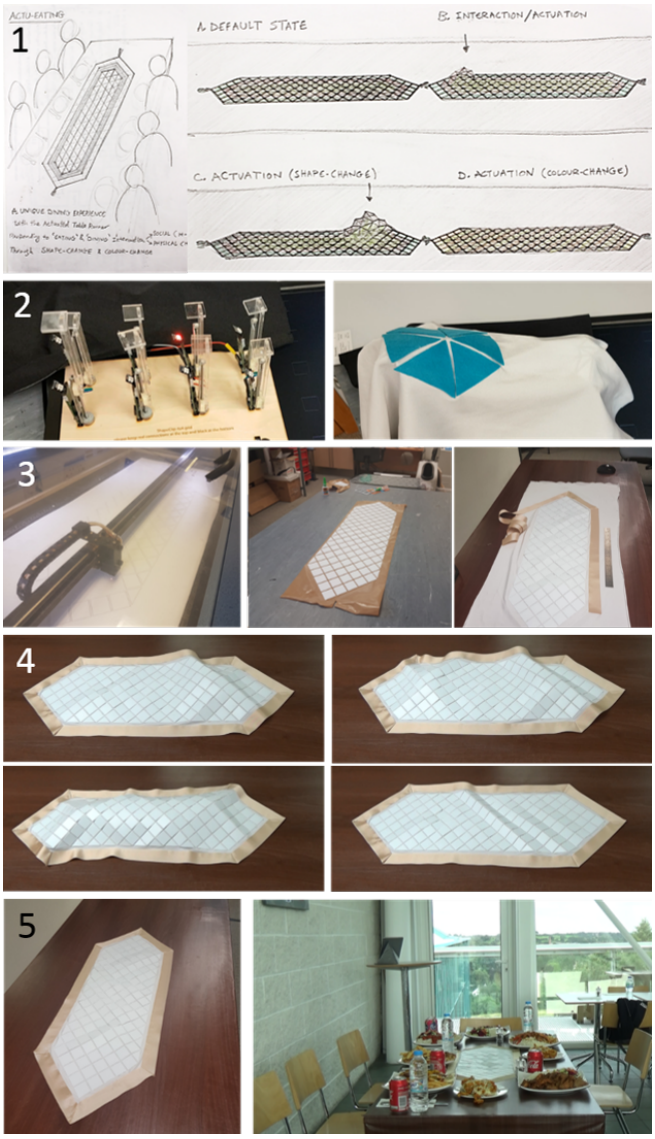

Figure 2. Designing and Making of Actuating1. 1) Ideation and Sketching. 2) Prototyping the Software and Hardware.3) Designing the Pattern. 4) Creating the Actuations. 5) ActuEater is ready and 'dinner is served'.

Interaction Repertoire

The eventual actuations performed by ActuEater1 were prototyped, live, in a WoO study (detailed below). The experimenter (first author) responded to emerging interactions and developed the following pattern of responses to users: when one participant was engaged with ActuEater1 or touched it, it vibrated (low actuation) the part in front of her/him by moving up and down in a small scale with limited height. When two participants were both engaged with it (talking about it with each other), it would vibrate in front of both of them. If two people touched it with their hands or used an object, it rose all up. Then if they tapped it, it went all down. If two or more people kept touching it, it animated in an organic wave motion going up and down from one end to the other. We were able to improvise actuations at some points to initiate interactions with one (or more) of the participants to explore the effects of this on their reactions to ActuEater1 and interactions with each other. For instance, a sequential low actuation can train from one end to the other if ActuEater1 'got bored of people ignoring it'. To allow for discoverability, we controlled the height of actuations to increase over time and usage, to see whether people will relate their interaction with the increase of deformation.

STUDYING ACTUEATER1

An initial evaluation study (A) took place in a terraced-rooftop restaurant with a group of 6 friends (P1-P6), with mixed genders (2F / 4M), age-groups and backgrounds (Media, Design, Economics, Computing, Chemistry and Psychology) who signed-up to participate in the study. Participants were not briefed as to what to expect beyond their voluntary participation in a study over a dinner meal. The meal was audio-video recorded from two different angles to capture as many of the users' expressions, interactions and conversations as possible. The dinner lasted about an hour, then we joined participants for a post-study 'design crit', a group discussion, lasting 30 mins where participants had the opportunity to express their reflections on their experience and provide us with critical feedback on our design and further design opportunities.

EVOLUTION OF THE ACTUEATER

Study A suggested a number of user-desired potential developments to ActuEater1: 1) Control: not be remotely-controlled and be legible (they assumed it was randomly actuating because human control (WoO) was not always immediate and consistent to all 6 participants); 2) Interaction: be responsive to their physical interactions (e.g. touch and physical objects); 3) Hardware: not to have such a bulky structure, loud noise or create a hole in the table; 4) Aesthetics: blend with the surrounding space and be more colourful; 5) Capabilities: colour-change was suggested to complement and enrich the shape-change; 6) Experience: be entertaining/ dancing, autonomous (have agency of its own), and interact with the surrounding space (music, objects); and 7) Meaning/ value: reveal/support further values (believing ActuEater1 had a hidden agenda of some good intention and meaningful purpose).

Therefore, we designed ActuEater2 to be a silent stand-alone fabric runner (with no motors required beneath the table) that is touch-sensitive and still has some agency designed to be more colourful with colour-changing capabilities (as well as shape-changing). Then further studies should then inform our research about how these changes affected the experience to show what meanings and values would people draw from their experience with ActuEater2. These further studies should give more insights on other findings i.e. social engagement, interaction repertoire, physical manipulations, and seamful/seamless sensing beyond interaction boundaries.

DESIGNING ACTUEATER2

In response to the suggested evolutions of ActuEater1, we developed ActuEater2 to have more organic actuations (rather than mechanical ones), direct physical interactions (rather than WoO), and richer capabilities (colour-change as well as shape-change). The redesign also shifted us away from demanding, bulky and noisy hardware (requiring a big hole in the table). Broadly speaking, ActuEater2 was intended to not be a radical departure from the design of ActuEater1, but build upon what we had learnt in terms of both design and user experience. ActuEater2 presented an organically-actuating soft decorative object which we could use to further study how multi-aesthetic interactions from a shape-changing decorative could impact people's experience of a given interior space/activity over time.

Making

ActuEater2 (see Figure 3) is a 60×40 cm cotton fabric envelope, with a stretchable spandex top holding the deformable pattern, both sandwiching a silicon rubber layer in between, holding a set of SMA (Shape Memory Alloy) wires. This layering technique was inspired by the HotFlex [15] technique for making interactive printed objects, which proved to achieve better results allowing ActuEater2 to be malleable enough to deform yet firm enough to relax again. Moreover, the layering acted as an insulating cover for the SMAs (a useful safety feature). The 9 SMAs used were each 1-inch pretrained shape-changing 'nitinol' shape-memory springs from Kelloggs Research Labs that actuate at 'standard temperature' (45°C) or equivalent 5V and 0.7A drawn from a MOSFET transistor, pulling it back to its 1-inch spring shape from any malleable form. ActuEater2 also had capacitive sensing parts (green flowers) using 10×10 cm concealed knit conductive fabric to enable soft touch and proximity sensing through $1M\Omega$ resistors. We used an Arduino microcontroller to program ActuEater2 and control the behaviour of its interactions.

As nitinol SMA springs are not solderable, we used a crimping technique where we carefully attached to both ends of each spring a conductive (silver) crimp bead to form a connection with an insulated copper wire. Through this crimping, we were able to connect and control SMA springs through the Arduino, which was sleaved and concealed out of user sight. We found that stitching the ends of SMA carefully to the fabric gives it better grip force to 'pull' it upwards without moving freely elsewhere. As SMA 'one-way' springs work by shrinking with heat or current, it crumbles the fabric in between both ends it is stitched to creating deformations. The weight of the runner and force of gravity then brings it back slowly to the table. Working out a perfect material weight that could be light-enough to deform with SMA, but still be heavy-enough to return to flat, was key to achieving a 'two-way' actuation. Moreover, this

meant that the most perceivable deformations were the ones stitched to the edges of the runner, not in the centre, where the weight is maximum, preventing visible deformation. Finally, to entirely conceal 'technology' from visibility, ActuEater2 was carefully finished using a sewing machine where we enclosed all its core components with nothing visible other than a power cable (that is replaceable with a Lipo battery).

Similar to ActuEater1, we designed ActuEater2 with a uniform custom-designed pattern laser-cut on 0.8 mm thin polypropylene sheets to give it a controlled semi-flexible moving capability. This time we optimized the pattern into triangular tessellation (instead of squares) to allow more organic deformations in different orientations. ActuEater2 was also designed to be more colourful. Thermochromic 'grey' fabric was used in some parts to add the capability of colour-change. By embedding a heating wire underneath, the thermochromic fabric was controlled to reveal a hidden pattern as an ambient display and means of richer interactivity.

Actuations

ActuEater2 changes shape more subtly, slowly and silently than ActuEater1, making it appear far more organic and less mechanical. Different parts of ActuEater2 behaved in different ways according to the affordance, stiffness and weight of the material at differing points i.e. edges deformed more freely than the centre. Touch-sensitive 'green' parts acted as ubiquitous sensing that triggered actuation of parts beside it. Agency was also enabled in the algorithm of ActuEater2 to display autonomous actuations if ignored for some time. Similar to ActuEater1, during the testing phase we realized that when ActuEater2 goes back to the default state, it also does not return entirely flat, again leaving unintentional traces showing a potentially interesting/useful 'history' of interaction.

STUDYING ACTUEATER2

We studied ActuEater2 in-situ, using methods and settings consistent with Study A (ActuEater1). We successfully ran 3 sessions with a total of 13 participants. We varied location for the meals to enhance the ecological validity of our exploration. The first (Study B) took place in a Lebanese restaurant (evening meal) with a group of 4 Middle-Eastern friends (1F, 3M) with backgrounds in Psychiatry, Health-care, Business and Biotechnology (P7-P10). The second (Study C) took place in a University cafe (lunch followed by tea and cake) with a South-Eastern Asian group of 5 female friends with backgrounds in Business, Computing, Architecture (2) and Dentistry (P11-P15). Finally, the third (Study D) was a dinner party at home (evening meal), where a group of 4 mixed international friends (2F, 2M) with backgrounds in Education, Social Work, Business and Civil Engineering (P16-P19) met at P18's home.

In all three studies, participants were not briefed about the ActuEater, or that is was an interactive artefact to give them the chance of having their meal as usual and discovering the ActuEater themselves. Although we purposely had participants from different cultures, backgrounds and age groups, we observed clear consistencies in most people's behaviour around ActuEater2 across groups. In both study B and C, the 'waiter' and 'waitress' were unexpected participants, where

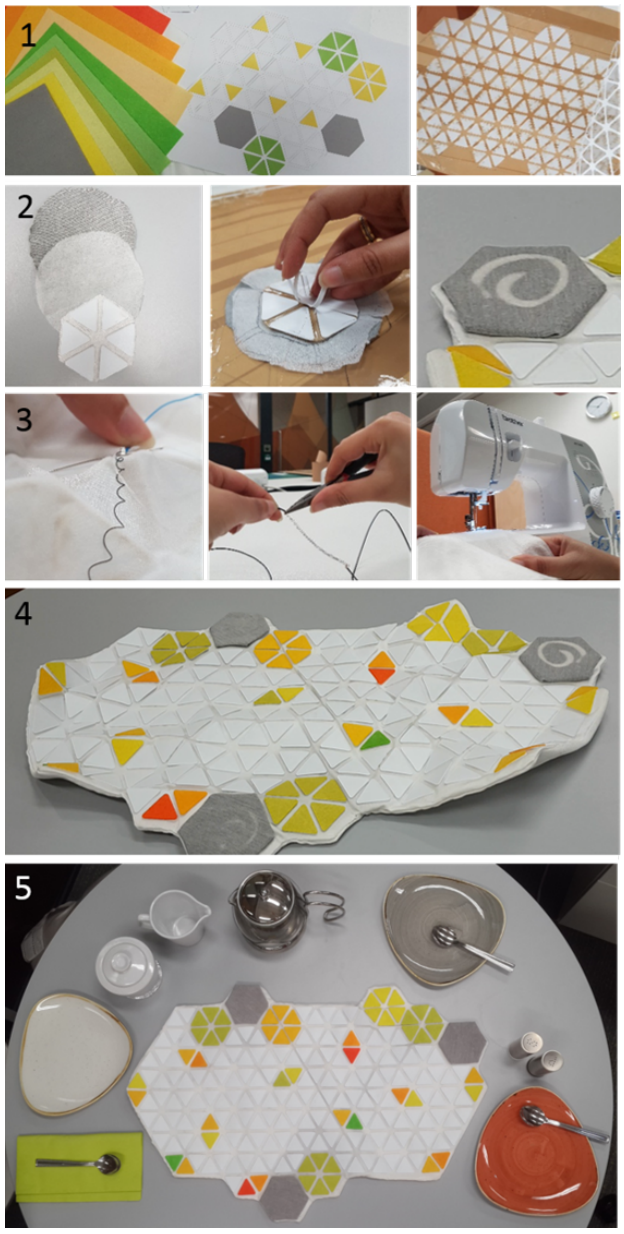

Figure 3. Designing and Making of Actuater2. 1) Designing the Pattern. 2) Making the Colour-changing parts. 3) Stitching, Crimping and Sewing. 4) Creating the Actuations. 5) ActuEater2 is ready.

the ActuEater responded to them whilst placing appetizers in the centre of the table (on top of ActuEater2). In study C, we hacked the sugar pot, plates, cinnamon and chocolate powder shakers, and the teapot, to be all capacitive, using stainless steel frames or aluminium foil bottom layer, and therefore interacting with ActuEater2. In study D, the home owner i.e. host dealt confidently with ActuEater2 in which she replaced objects and plates on top of it as she pleased, and lifted the ActuEater and re-positioned it on her dining table.

As in study A, meals were audio-video recorded from multiple angles to capture users' expressions, interactions and conversations. After each meal a design crit group discussion was held to critically evaluate the design of our ActuEaters in terms of: 1) Sense-making and interpretation (how did

ActuEater make them think? Does ActuEater look, feel and sound right?); 2) Interaction and emotional engagement they had with ActuEater, and with each other in relation to it; 3) Complex scenarios and interactions beyond expected legible interactivity; 4) Proposing possible enhancements (in terms of design, interaction, purpose, meaning/value and/or context) in light of: constructive feedback about the design itself; materiality (evaluating the material quality and finish), and pros and cons (what is bad and what is good about the design). Data from the meals and the post-meal design crits was transcribed and then subjected to Thematic Analysis [3].

UNDERSTANDING THE ACTUEATING EXPERIENCE

In this section, we discuss the results of our thematic analysis drawing on the data from all four of our in-situ studies (A-D incorporating both ActuEater 1 and 2). Our orientation to use a 'situated design crit' as an evaluatory mechanism means that the emphasis of our results is less on the 'dining experience' and more on a critical reflection on the design of the ActuEater. Accordingly, the themes we discuss unpack the ActuEating experience, exploring how users made sense of both ActuEaters, and how they imagine they could be better designed, used or employed.

Experience Sense-Making

Describing the Experience

People made sense of our actuating decoratives in various ways. While ActuEater1 was described as *"an attention seeker, not distracting in a bad way, it's more of an interesting distraction."* (P4), ActuEater2 was more *"subtle, it can take the attention, but not all the attention."* (P7) described: *"like a cherry on top, just a nice part of our conversation, but not focus demanding"* (P10). Variously, the ActuEaters were seen as conversation-starters, e.g. *"an ice-breaker* (P13) and *"an interesting talking piece"* (P5). But some focused more on its enigmatic qualities framing it as *"very creative and interesting"* (P8), *"revolutionary"* (P7), *"mysterious, quite alive"* (P19), *"unbelievable"* (P17) and *"an object of curiosity"* (P16). However, we understand how this was largely driven by its novelty effect. Nevertheless, some saw immediately entertaining qualities in the ActuEater suggesting it was playful like a *"treasure box"* (P12), a board game and generally *"fun and entertaining"* (P11). Whilst others saw it as something more meditative *"like a water fountain"* (P1) and *"calming like ocean waves"* (P8), and *"great to meditate or gaze at, like a fireplace"* (P7). When describing some of the deformations and interactions of ActuEater1, participants used more mechanical terms like *paused, rested, nudging, popping and poking, all go up, moving across and slow down*. Whilst, ActuEater2 was defined in perhaps more fluid terms as *changing, moving, crumbling, dancing* and *"it's almost like breathing!"* (P18).

Understanding the WHY

Understanding interactions with the ActuEater had clearly occupied a great portion of the conversation among participants over their meal. Some discussed how it might be proximity/motion sensing, and not any touch, but the way they touch it *"that's why when I touch it, it goes brighter than when you touch it, you have to calm down P12, see, if you're gentle to it, it responds"* (P13). Also, sound-sensing was frequently suggested and tested with its different versions: *voice*, *volume* or *conversation engagement*, *restaurant music*, *cutlery sound*, *noise in the environment*, or even *keywords*, all assuming it is *"physicalizing it (sound)"* (P2). Although it responded to their touch and physical interactions, some suggested further para-sensing beyond that, wondering if it picked up their *"heat, or energy"* (P19), *"mood"* (P12), *"stress"* (P13), *"brain waves or heartbeat"* (P16). To validate their theories, participants tested their ideas in different ways: group D gathered around it covering it up to warm it with their hands in a spiritual manner, group B and C 'clicked' it together on different parts simultaneously, while group A patted it together like a pet.

Perceiving the Meaning & Value

Besides its entertaining aspects, participants were keen to give ActuEater further values believing it had a hidden agenda of some good intention and meaningful purpose. Group A questioned *"Was it to do with how engaged you are in the conversation?"* (P2), *"or is it kinda 'stop eating' and 'talk to people'?"* (P1), *"It did try to nudge me because I was so focused while eating."* (P6), *"or maybe it's just trying to bring us all together"* (P2). Likewise, group B suggested how it could be a good conversation starter if people are not quite friends, group C also expressed it is a way to help people interact with each other, and group D argued that: *"it could be interactive with people who speak the most or speak the least, because I finished my food, that's why it is reacting more on my side"* (P19). Through conversations, participants were building assumptions that ActuEater was a resource for social engagement. Participants' responses implied how they thought ActuEater 'wanted' them to engage with each other and sought to develop a deeper social interaction amongst them.

Envisioning the Concept

The overall experience of ActuEating helped us better understand how decorative artefacts, or 'decoractives', can uplift the state-of-the-art to a new level. Envisioning decoractives in general can be drawn from participants' comments about the ActuEaters in the design crits as an abstract concept for interactive decorative artefacts in general, not specifically a table runner. For instance, participants' thinking about the broader relevance and use of decoractives was describing in study C as *"the fun part of the boring life"* (P11) elaborating on how such aesthetic interaction allows people to have fun with objects that they might not actually take notice of on a daily basis. In study B, P7 also ensured that the ActuEating experience changed his perspective about decorative objects, furniture and aesthetics in general. Moreover, in study D, P16 highlighted how *"the best value is the merge of technology where everyday objects can do more things and react to our presence and actions"*. In this sense, we need to start exploring other decorative objects and investigate ways they can be of further purposes, meanings and values to people beyond their static aesthetics.

Evolution of Interaction

Users' Roles

Participants' desire to interact with the ActuEater ranged from reluctant to frequent. During the 4 studies, participants created

similar scenarios, engaging with ActuEaters through three different roles: 1) the 'explorer' role who was actively engaging and frequently interacting (9/19 participants); 2) the 'observer' closely watching in a spectator role and occasionally interacting with ActuEaters (6/19 participants), and 3) the 'bystander' role of those who rarely touched it and were reluctant to take part in 'physically' exploring it (4/19 participants). Particularly one in each group was a bystander/reluctant to touch it or look at it, yet still reflecting on it and analyzing its behaviour. Observers analyzed every interaction and assumed meanings and interpreted its actuations. Despite their different roles and positions, all participants at some point during the 4 studies attempted to explore ActuEaters either physically, by finger touching, poking, hand patting, lifting up the fabric off the table, or looking down under the table to realize what is causing the shape-change.

Social Engagement

The way participants responded to and interacted with the ActuEater varied over time and for different situations, bringing opportunities for rich social engagement. They frequently exchanged eye-contact when it moved, especially those adjacent to the moving part, expressing it felt as a personal message for them, while exchanging smiles, laughs and jokes about it, acknowledging their amusement, surprise and enjoyment of its unexpected behaviour. Four female participants were observed taking photos of their ActuEating experience using their smart phones to share on social media. Three or more participants often physically explored the ActuEater together, which made them establish social engagement around it. For example, both P2 and P5 kept their hands on ActuEater1, together, while smiling for a while, as it was actuating, enjoying the feeling of it going up and down. With ActuEater2, several participants touched 'similar' parts simultaneously to explore it together imitating each other's interactions from gentle touches to firm pressing strokes. As actuations varied, participants were developing interactions together in a self-learning exploratory process, learning from each other in playful ways, collaborating and exchanging techniques. E.g. *"wait, if we touch one by one together, what will happen?"* (P13), *"let's press it together at the same time"* (P10 to P7). On a few occasions, some would interact on behalf of others when they felt that the ActuEater needed to be responded to but was being ignored.

Physical Manipulations

Once ActuEater1 had gained users attention it attracted their touch interactions (first fingertip touch, then hand and palm touch), initially passive (responding to) then active (initiating) interaction. Then interactions went beyond touch into more physical 3D manipulations according to the shape, material and its affordance (such as grasp, pat, squeeze, bend, etc), see Figure 4. After thoroughly exploring direct physical interactions, participants became more creative. For instance, P1, P3 and P5 used water bottles, salt shakers and mobile phones to place onto ActuEater1 to explore its response. Further exploration with ActuEater2 brought richer physical manipulations to the table. For example, many participants frequently touched the coloured 'felt' parts with a brushing stroke on its soft texture, although these elements weren't sensitive. 'Hover' hand in-air gestures above sensitive parts were used by all groups when proximity-sensing was realized. Some covered up thermochromic parts with both hands to 'feel the heat'. Some lent forward or backwards in their seats to test proximity. Some repositioned physical objects (that were initially placed randomly) precisely on particular parts of ActuEater2 to test them. Many were observed 'tracing' the colour-changing pattern with one finger in a continuous satisfying way.

Figure 4. Interactions with ActuEater1 (left) and ActuEater2 (right)

Physical interactions were quite directly proportional with actuations in terms of scale. That is, we noticed that they responded to located (small) low actuations of ActuEater1 by one fingertip, higher ones with their three middle fingers, and when it was all up, they used their whole palms. ActuEater2 was definitely manipulated more intensely, it was flipped over or pulled off the table, bent, felt and squeezed, and perceived more like a 'fabric' runner than as a shape-changing device like ActuEater1. This reflects how people develop their own interactions based on their own perceptions, interpretations, backgrounds and instincts. Yet, people learn together and from each other, developing their ideas, perceptions and engagements with a certain artefact.

A Complex Behavioural Repertoire

Beyond the Boundaries

Several participants had an irresistible urge to 'tidy up' both ActuEaters after actuations by flattening the 'history wrinkles' that were created by its actuation. This physical interaction (maybe due to neatness or maybe expecting a default state of being totally flat) triggered more actuations thereafter. Observing how participants took extra effort to interact with it (e.g. stretch out their arms to reach it, put down cutlery, etc) shows their 'willingness' to physically engage with it. Interacting blindly with it (without even looking at it) shows 'expertise' and confidence. Participants not only interacted with the actuating parts of ActuEaters, but they tended to explore the boundaries of sensitivity to discover the edges of 'seamless and seamful' interaction, evident by manipulating even the satin ribbon edge of ActuEater1 and the plain senseless petals of ActuEater2.

'Interaction Boundaries' were even crossed to explore other potential means of engagement. For example, ActuEater2 received several 'voice commands' to test speech as possible input interaction: *"Hi" (P12, P13), "Move" (P13), "By the power in me, rise!" (P8).* At the end of study B, P10 held its edge with a firm grip and shook hands with ActuEater2 saying *"nice to meet you"*. Participants often felt an urge to initiate interaction with ActuEaters deliberately, when they were not actuating, driven by an inner desire to have fun through playing and to find out more about how it works. This creates space

for contradicting scenarios where they want to stop it when it's up/active, and yet they wanted it active when it sleeps. Such complicated behaviour resembles typical interactions with pets or children: when quiet, we want to play with them, but when they are manic, we wish them calm. It can also explain participants' tender 'pat' interaction, as their way to calm it down, revealing a zoomorphic interpretation of the actuations. *"stroke it carefully, it's like your pet!"* (P13). Others showed further 'empathy' towards it: *"you should just touch it, not squeeze it like that"* (P7 to P10).

Curiosity and Mystery

Curiosity was evident in all four studies, where participants explored and talked about how it works, and sneaked a peek underneath. Every participant at some point picked the table runner up from the table, pressed it to feel its inner body, or bent downwards to look underneath the table. ActuEater1 obviously had the shape-changing mechanism under the table and participants commented on how it would be more practical not to have a hole in the table *"and keep all the mystery alive, because you look under the table and oh no, it must be in the runner!"* (P4), *"what kind of sorcery would this be!"* (P6).

Accordingly, we designed ActuEater2 to be self-actuating using SMA wires which caused participants to flip it, bend it and pull it off the table to ensure there is nothing underneath, then squeeze it and press it to feel what is inside. P10 put his hand underneath the table below ActuEater2 testing if the capacitive sensing would work through the glass downwards. P17 'rolled' it firmly to realize its affordance and materiality when others wondered whether there was something inside it. Participants expressed a mysterious aspect not just in the movement but also in the colour-change: *"notice those colouring spirals again, it doesn't look like an electrical light"* (P18), *"It is totally unexpected, it would never cross my mind that a table fabric can actuate like this. I wonder how it changes? what causes the colour-change? and how does this pattern reveal?"* (P7). This shows us how people think about inter-weaving technology into everyday objects in a hidden way and how it is more 'magical' from a user perspective.

Discoverability and Illegibility

Designing for discoverability by 'hiding the interaction' creates a variable and playful repertoire of behaviours, while designing for illegibility (non-obvious and inconsistent) by 'hiding the logic' creates a sense of autonomy and a spatio-temporal aspect of 'Interioraction' [27]. In our research we wanted to explore these design directions where discoverable and illegible systems could be perceived as mysterious and magical. During the initial study, participants criticized ActuEater1 for not having an immediate consistent response to their actions. Although there was a specific pattern mapping inputs to outputs, participants expressed how they still require an explicit cue to fully understand. Apparently, ActuEater1 made participants of study A feel unconfident about its illegible and discoverable interactions, when some autonomous interactions were perceived as random. Participants not only expressed how legibility is easier to relate to, but also how a level of control over ActuEater1 was desirable.

As a result, we designed ActuEater2 to be both sensing (and reacting) and autonomous at the same time, which was appreciated in the design crits: *"It's nice to have some control of it and it is also nice that it does its own thing by itself as well"* (P18). In addition to direct and immediate input-output relationships, we explored participants' view of the artefact's behaviour that evolves with their interactions over time and usage, instrumenting discoverable interaction as an adventure: *"was it moving that much from the beginning?"* (P10), *"as we talk about it more, it moves more"* (P9), *"we'll keep playing with it and at the end we'll find out it's a Jumanji!"* (P13), *"or find the treasure"* (P12). *"it could evolve more over our dinner party and break out a dance at the end to celebrate!"* (P16). This shows how people were readily orienting to a world where objects known to be static cannot only change over time, but can change unexpectedly and in an adventurous manner with different paces, taking various forms, that could be ultimately rewarding.

Design Explorations

During their group discussion in the design crits, participants suggested many enrichments to both ActuEaters and proposed other functional and aesthetic possibilities. They also proposed different artefacts that could be similarly interactive and suggested other types of spaces where they believed it might be interesting to interact, adopt and utilize such technology.

Proposed Functions

Participants focused their suggestions of potential functions on three main themes: 1) extending, 2) engaging, and 3) entertaining. 1) 'Extending' decorative objects by augmenting them with further capabilities was suggested as an alternative to smart devices and gadgets, e.g. *"now we're getting into an era where we expect objects to be that smart and you can just talk to them and tell them what to do"*, *"so Alexa should be part of my decor and have more interactive capabilities than activating heating or obeying commands"* (P16); 2) 'Engagement' was frequently mentioned for i) bringing people together and provoking social engagement, or ii) occupying people waiting for something or feeling lonely, iii) engaging children in different situations such as doctors' waiting rooms, and iv) creating an ice-breaking object for those meeting for the first time; and 3) 'Entertainment' and stimulating was also discussed as a useful purpose for such an object as: *"it is great for an absent mind to meditate or gaze at"* (P10), *"gives a sense of calmness.. I can keep looking at it for hours"* (P7), *"it reduces stress, like a fidget-spinner"* (P12) and *"stimulating curiosity of children, how is it moving and changing colour?"* (P7). P13 expressed a similar functional quality of keeping children entertained without a digital screen i.e. a display-less display, and P18 suggested a changing wall-art that entertains, but unlike a TV set, is not focus demanding. All these functions represent the value of non-demanding and non-disrupting technology (people aspire for) that keeps the essence of social quality time and adds a bonus dessert to it.

Proposed Artefacts

As they perceived it as a gaze-drawing object, some participants suggested other artefacts that could be similarly (or more) interesting. Some suggested other flat surfaces such as

"colour-changing coasters or placemats that entertain me until the next course, or warms my plate" (P10), *"a mat or a rug on the floor that we sit on and crumbles when one moves away"* (P11), *"a seat that changes colour the more you stay sitting down too long then moves urging you to get up"* (P15) and *"a mirror or a painting"* (P4). P7 imagined wall-art that gives different shadows or shapes responding to proximity and an entire wall that autonomously reveals and moves parts such as butterfly wings decorating the wall to actuate his home decor. Moreover, others suggested 3D objects such as *"a playful sculpture"* (P16), *"a moving vase"* (P9), *"a pillow to help my neck problems"* (P11), *"a lampshade that starts dancing like this when I'm in a 'dancey' mood"* (P7), *"a coffee table itself"* (P18, P5), *"a blanket that crumbles around you would be great to give you warmth"* (P7).

Proposed Interactive Aesthetics

A crucial aspect of decorative artefacts is their need to blend-in to complement an interior style and are usually matching other objects in the same space. Therefore, we were keen to choose settings where the ActuEaters could fit-in and complement those spaces with matching objects, such as matching tableware, interior colour-scheme and style (as much as possible): *"I didn't notice anything weird at first as it had the same colours of the restaurant chairs and napkins, and petals shape are the same as the table glass engravings."* (P7). However, more tailored design for all details has to be carried out for each individual space, e.g. *"It looks elegant and the colours are matching but the shape has to be round because the table is round"* (P13), while some saw it as a *"futuristic design"* (P10, P17) preferring more traditional aesthetics.

Although we carefully eliminated any LEDs from ActuEater1 to keep it as normal and traditional as possible, 4 of our 6 participants expressed how they expected/wanted ActuEater1 to have 'lights'. This indicates how they do not entirely perceive it as a (normal) table-runner, but as a 'digital' object. When they were asked about colour-changing capabilities instead of lights (e.g. using thermochromic inks), they showed excitement and suggested that colour-change could complement and enrich the shape-change, adding *"a more interesting layer"* (P3). When we enabled thermochromic colour-change in some parts of ActuEater2, they suggested that all petals should change colour and recommended hydrochromics as well *"if it responds to water or spilt liquids, it would turn an embarrassing bad situation into an interesting conversation re-starter"* (P9). Other richer multi-aesthetic interactions suggested that petals could move freely and blossom in 3D, or it plays music and amplifies itself with the volume to *"hit as many senses as possible"* (P16).

Proposed Environments

In terms of spaces, participants proposed different environments in which they envisioned such technology. Restaurants and silent spaces such as libraries, museums, clinics, waiting rooms and specifically waiting areas at the doctors' surgeries to entertain people while waiting, were proposed by several participants across the 4 studies. Other proposed environments, included classrooms as a board that *"attracts focus of students"* (P12), toilets *"instead of reading the shampoo ingredients if you forget your smart phone"* (P6) and office spaces *"to distract from work, to refresh, take a breath and de-stress"* (P12), but *"not in a formal setting as meeting rooms, it becomes distracting"* (P11). Alternatively, having them in homes was debatable. Some expressed their worry about the finite number of actuations that wear its novelty out too quickly for home occupants, but still found it exquisite and delightful for their guests. So careful design should create actuating capabilities that makes it 'sustainably interesting'. Others saw it *"as a creative or a special object that you'd like to display"* (P8) and saw opportunities in which a domestic artefact can change colour based on ambient temperature or display household data such as water or energy consumption.

DESIGN OPPORTUNITIES

Our exploration of critical responses to the ActuEater has suggested a number of key learnings which we highlight below in the form of a set of design opportunities to consider when designing interactive decoratives. We should *design for*:

- Meaningfulness: Although people acknowledge that decorative objects are for aesthetic purposes, not necessarily functional, they still give them purpose in terms of *meanings* and *values*. This applies to 'decoractives' as well where people interpret their *overall experience* in deeper meanings and give a purposeful value to the actuations often beyond what was designed for (in either positive or negative ways), which is a design feature to be exploited.

- Spatiality: When technology blends into our daily environment, people perceive it as part of their overall *spatial experience* and expect it to interact with the space, relating shape-changes to factors beyond their direct input such as music, conversation topics, space occupancy, weather, etc. This does not apply to digital devices that do not blend in, but stand out, requiring full attention of users.

- Sociability: *Social engagement* around an actuating artefact is rich in terms of the noticeable exploratory, collaborative and playful nature of how people interact with such technology together. This should inspire designers investigating this design space, shaping how interactive interior elements might be dealt with to utilize and support sociability.

- Tactility: Evident by how ActuEaters attracted touch, hand manipulations and *physical interaction* through other objects, designers should seize this opportunity to design for tactility utilizing the intuitive affordance of different material textures and physical objects already in the space.

- Seamlessness: People anticipate shape-changing interfaces that are portable, weavable and seamlessly hidden (instead of bulky, cabled and demanding machines), stimulating their sense of *curiosity and mystery*, believing it would be magical and more efficient in terms of everyday use in their normal environments. There is a great opportunity to augment existing artefacts with shape-changing materials instead of embedding mechanical solutions within them.

- Beyondness: Actuating decoratives are explored *beyond the boundaries* of designed interactions, where people navigate

away from observed sensors and cruise through new possibilities, from voice and gestures to shaking hands. Unlike robotic SCIs, when designing organic actuations (smooth and malleable), people will tend to develop a notion of empathy and tenderness in their interactions with it, even with no designed zoomorphic shape, texture or sound, people still believe it has a body, mood and intentions.

- Discoverability: Systems that are not consistent and obvious, but enable actuations to evolve over time or usage can be misleading, incomprehensible, or perceived as random. However, careful iterative design and the use of situated studies (beyond minutes) can create opportunities for designers to explore novel possibilities and *mysterious designs* that promote discoverability in actuating interiors, to increase *adventurous exploration* of artefacts.

- Significance: Designing decorative objects that are useful through *potential functions*, creates a greater value to them. Through slow interaction and calm technology, we can (and should) make decoractives with 'extended' functionalities, beyond their aesthetics, 'engaging' people together through artefacts and 'entertaining' them with their multi-aesthetics in diverse and novel ways.

- Match-making: As decorative objects usually have other matching items in the same interior space (to blend and complement the space aesthetics and style), people relate these relationships intuitively. Therefore, when designing 'decoractives', we can utilize such relationships in developing spatial interactions (with different elements in the space) such as our *proposed artefacts* creating a rather richer experience, e.g. a matching cushion and throw, or a curtain with a rug, can interact together or through each other.

- Colourfulness: People expect shape-changing interfaces, especially decorative ones, to be colour-changing as one of their main *proposed aesthetics*, even through lights. A good design practice to create *display-less displays* is to embed colour-changing properties in the material itself instead of using lights (e.g. thermochromic or photochromic inks) as means of both sustainable actuation and spatial interaction.

- Blending-in: Shape-changing interfaces can enhance the social experience of a group of people in different *potential environments*. In a given context, when designed to blend into their environment (instead of standing out as a separate device), people can choose when to ignore it and when to use it together as a social probe, to talk about, interact with, and engage together through it.

DISCUSSION & CONCLUSION

In this paper, we presented a series of design explorations, critically examining the potential use of shape-changing materials in the design of interactive decorative artefacts. We believe our work provides an inspiring case-study supporting others who might wish to design and develop actuating decorative artefacts for different contexts and cultures. The ActuEating study offered an open-ended set of observations in terms of user behaviour, interpretation, reactions and expectations. The intention wasn't studying the dining experience in itself, but to explore the design of interactive artefacts and how people may perceive, interact with and experience such technologies in relevant settings and to gain deeper knowledge and insight into designing interactive everyday objects as decorative artefacts.

As with both coMotion [17] and the History-Tablecloth [12], the improvised interactivity and often confusing behaviours, added value and richness to the ActuEating experience in ways that had not been anticipated, allowing for complex interpretations. While controlling ActuEater1 from behind the scenes, we learnt how participants collaborated to realize how to control it themselves, not just theorizing what triggers it, but by testing different input interactions beyond our expectations. We then designed ActuEater2 to be both physically-interactive and autonomous. From voice commands, knocking on the table and observing music patterns, to stroking, patting and using other objects (e.g. teapots, salt, sugar and phones) on top of it, participants developed interactions themselves through social engagement to explore its potentials, interaction boundaries and limitations. Despite the 'engaging' and 'entertaining' benefits realized by the ActuEating studies, we understand the limitations in terms of the effect of 'novelty' on user experience, and are planning to address this in our future work.

The challenges we faced to conceal technology within an everyday fabric artefact ubiquitously, were aimed at experimenting how hidden interactivity in objects (that blend into the space design) could be of value, meaning and significance to space occupants over an in-situ social event (in a restaurant or at home). We emphasize on how weaving technology into real-world objects, specifically decorative ones, can deliver a rather richer 'spatial experience' in a given contextual setting. By taking previous work further, we were able to explore new territories of this design space. However, the design constraints we set included studying only actuating table runners in dining settings. Further research should explore other artefacts, in other contexts, to realize the latent and intrinsic potentials of extending their capabilities, seamlessly. Although ActuEaters were designed as non-functional artefacts, their aesthetic qualities as decorative objects are rather useful as they don't need constant attention, which aligns well with slow and calm technology concepts [30].

This work will help advance and continue the research commenced by the HistoryTableCloth [12] and coMotion [17] around shape-changing interfaces and interactive spaces, furniture and everyday objects. The beauty of interactive decorative objects (unlike novel gadgets) is that whether they interact (accurately or entirely) or not, the object still has value. Its failure to interact at any time will not lead to a crisis of affordance [12], as it remains a decorative aesthetic artefact in its own right. Our work points to the future potential of new materialities, merging interaction design with interior design.

ACKNOWLEDGEMENTS

We would like to thank all our participants who volunteered to this study. This research was partially-funded by the UK's EPSRC MORPHED Project (award EP/M016528/1) and Newcastle University SAgE DTA programme.

REFERENCES

1. Pollie Barden, Rob Comber, David Green, Daniel Jackson, Cassim Ladha, Tom Bartindale, Nick Bryan-kinns, Tony Stockman, and Patrick Olivier. 2012. Telematic Dinner Party: Designing for Togetherness through Play and Performance. In *Proceedings of the 2012 Conference on Designing Interactive Systems (DIS'12)*. Newcastle, UK, 38–47. https://doi.org/10.1145/2317956.2317964
2. Alice Bodanzky. 2012. Exploring the Expressiveness of Shape-Changing Surfaces. In *Proceedings of the Sixth International Conference on Tangible, Embedded, and Embodied Interaction (TEI'12)*. Kingston, ON, Canada, 403–404. DOI: http://dx.doi.org/10.1145/2148131.2148235
3. Virginia Braun and Victoria Clarke. 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. DOI: http://dx.doi.org/10.1191/1478088706qp063oa
4. Jaz Hee-jeong Choi, Marcus Foth, and Greg Hearn. 2014. *Eat, Cook, Grow: Mixing Human-Computer Interactions with Human-Food Interactions*. https://mitpress.mit.edu/books/eat-cook-grow
5. Marcelo Coelho and Jamie Zigelbaum. 2011. Shape-changing Interfaces. *Personal and Ubiquitous Computing* 15, 2 (2011). DOI: http://dx.doi.org/10.1007/s00779-010-0311-y
6. Nicholas S Dalton, Emily Collins, and Paul Marshall. 2015. Display Blindness? Looking Again at the Visibility of Situated Displays using Eye Tracking. In *Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems*. ACM, Seoul, Republic of Korea, 3889–3898. DOI: http://dx.doi.org/10.1145/2702123.2702150
7. Felecia Davis. 2015. The Textility of Emotion: A Study Relating Computational Textile Textural Expression to Emotion. In *C&C'15*, Vol. 2. Glasgow, United Kingdom, 1977–1982. DOI: http://dx.doi.org/10.1145/2702613.2732739
8. Felecia Davis, Asta Roseway, Erin Carroll, and Mary Czerwinski. 2013. Actuating Mood: Design of the Textile Mirror. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction (TEI'13)*. Barcelona, Spain, 99–106. DOI: http://dx.doi.org/10.1145/2460625.2460640
9. Aluna Everitt and Jason Alexander. 2017. PolySurface: A Design Approach for Rapid Prototyping of Shape-Changing Displays Using Semi-Solid Surfaces. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS'17)*. Edinburgh, UK, 1283–1294. http://dx.doi.org/10.1145/3064663.3064677
10. Hasan Shahid Ferdous, Frank Vetere, Hilary Davis, Bernd Ploderer, Kenton O Hara, Rob Comber, and Geremy Farr-wharton. 2017. Celebratory Technology to Orchestrate the Sharing of Devices and Stories during Family Mealtimes. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Denver, CO, USA, 6960–6972. https://doi.org/10.1145/3025453.3025492
11. Sean Follmer, Daniel Leithinger, Alex Olwal, and Akimitsu Hogge. 2013. inFORM: Dynamic Physical Affordances and Constraints through Shape and Object Actuation. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'13)*. St. Andrews, UK, 417–426. DOI: http://dx.doi.org/10.1145/2501988.2502032
12. William Gaver, John Bowers, Andy Boucher, Andy Law, Sarah Pennington, and Nicholas Villar. 2006. The History Tablecloth: Illuminating Domestic Activity. In *Proceedings of the 2006 Conference on Designing Interactive Systems (DIS'06)*. University Park, Pennsylvania, USA, 199–208. DOI: http://dx.doi.org/10.1145/1142405.1142437
13. William W Gaver. 2003. Ambiguity as a Resource for Design. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'03)*. Ft. Lauderdale, Florida, USA, 233–240. DOI: http://dx.doi.org/10.1145/642611.642653
14. Catherine Grevet, Anthony Tang, and Elizabeth Mynatt. 2012. Eating Alone, Together: New Forms of Commensality. In *Proceedings of the 17th ACM international conference on Supporting group work (GROUP '12)*. Sanibel Island, Florida, USA, 103–106. http://dx.doi.org/10.1145/2389176.2389192
15. Daniel Groeger and Elena Chong Loo. 2016. HotFlex: Post-print Customization of 3D Prints Using Embedded State Change. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'16)*. San Jose, CA, USA, 420–432. http://dx.doi.org/10.1145/2858036.2858191
16. Jens Emil Grønbæk, Henrik Korsgaard, Marianne Graves Petersen, Morten Henriksen Birk, and Peter Gall Krogh. 2017. Proxemic Transitions: Designing Shape-Changing Furniture for Informal Meetings. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'17)*. Denver, CO, USA, 7029–7041. http://dx.doi.org/10.1145/3025453.3025487
17. Erik Gronvall, Sofie Kinch, Marianne Graves Petersen, and Majken K. Rasmussen. 2014. Causing Commotion with a Shape-Changing Bench. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'14)*. Toronto, ON, Canada, 2559–2568. DOI:http://dx.doi.org/10.1145/2556288.2557360
18. John Hardy, Christian Weichel, Faisal Taher, John Vidler, and Jason Alexander. 2015. ShapeClip: Towards Rapid Prototyping with Shape-Changing Displays for Designers. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'15)*. Seoul, Republic of Korea, 19–28. DOI: http://dx.doi.org/10.1145/2702123.2702599

19. Alexis Hiniker, Sarita Y Schoenebeck, Ann Arbor, and Julie A Kientz. 2016. Not at the Dinner Table: Parents' and Children's Perspectives on Family Technology Rules. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)*. San Francisco, CA, USA, 1376–1389. https://doi.org/10.1145/2818048.2819940

20. Annika Hupfeld and Tom Rodden. 2012. Laying the Table for HCI: Uncovering Ecologies of Domestic Food Consumption. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. Austin, Texas, 119–128. http://dx.doi.org/10.1145/2207676.2207694

21. Hiroshi Ishii, David Lakatos, Leonardo Bonanni, and Jean-Baptiste Jb Labrune. 2012. Radical Atoms: Beyond Tangible Bits, Toward Transformable Materials. *Interactions* XIX, February (2012), 38–51. DOI: http://dx.doi.org/10.1145/2065327.2065337

22. Hiroshi Ishii, Daniel Leithinger, and Sean Follmer. 2015. TRANSFORM: Embodiment of "Radical Atoms" at Milano Design Week. In *CHI'15 Extended Abstracts*. Seoul, Republic of Korea. DOI: http://dx.doi.org/10.1145/2702613.2702969

23. Young Suk Lee. 2015. Spiky Starfish: Exploring 'Felt Technology' Through a Shape Changing Wearable Bag. In *Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction (TEI'15)*. Stanford, CA, USA, 419–420. DOI: http://dx.doi.org/10.1145/2677199.2690878

24. Sarah Mennicken, A.J. Bernheim Brush, Asta Roseway, and James Scott. 2014. Finding Roles for Interactive Furniture in Homes with EmotoCouch. In *Proceedings of Ubicomp'14 Adjunct*. Seattle, WA, USA, 923–930. DOI: http://dx.doi.org/10.1145/2638728.2641547

25. Robb Mitchell, Alexandra Papadimitriou, Youran You, and Laurens Boer. 2015. Really Eating Together: A Kinetic Table To Synchronise Social Dining Experiences. In *Proceedings of the 6th ACM Augmented Human International Conference (AH'15)*. ACM, Singapore, Singapore, 173–174. http://dx.doi.org/10.1145/2735711.2735822

26. Nadia Mounajjed and Imran A Zualkernan. 2011. From Simple Pleasure to Pleasurable Skin: An Interactive Architectural Screen. In *DPPI '11*. Milano, IT, 30–37. DOI:http://dx.doi.org/10.1145/2347504.2347537

27. Sara Nabil, David Kirk, Thomas Ploetz, Julie Trueman, David Chatting, Dmitry Dereshev, and Patrick Olivier. 2017a. Interioractive: Smart Materials in the Hands of Designers and Architects for Designing Interactive Interiors. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS'17)*. Edinburgh, UK, 379–390. http://doi.acm.org/10.1145/3064663.3064745

28. Sara Nabil, Thomas Ploetz, and David S Kirk. 2017b. Interactive Architecture: Exploring and Unwrapping the Potentials of Organic User Interfaces. In *Proceedings of the 11th International Conference on Tangible, Embedded, and Embodied Interaction (TEI'17)*. Yokohama, Japan, 89–100. DOI: http://dx.doi.org/10.1145/3024969.3024981

29. Mamoun Nawahdah. 2013. Virtually Dining Together in Time-Shifted Environment: KIZUNA Design. In *Proceedings of the 2013 conference on Computer supported cooperative work (CSCW '13)*. San Antonio, TX, USA, 779–788. https://doi.org/10.1145/2441776.2441863

30. William Odom, Richard Banks, Abigail Durrant, David Kirk, and James Pierce. 2012. Slow Technology: Critical Reflection and Future Directions. In *Proceedings of the 2012 Conference on Designing Interactive Systems (DIS'12)*. Newcastle, UK, 816–817. DOI: http://dx.doi.org/10.1145/2317956.2318088

31. William T. Odom, Abigail J. Sellen, Richard Banks, David S. Kirk, Tim Regan, Mark Selby, Jodi L. Forlizzi, and John Zimmerman. 2014. Designing for Slowness, Anticipation and Re-visitation: A Long Term Field Study of the Photobox. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*. Toronto, ON, Canada, 1961–1970. DOI: http://dx.doi.org/10.1145/2556288.2557178

32. Roshan Lalintha Peiris, Jeffrey Tzu Kwan Valino Koh, Mili John Tharakan, Owen Noel Newton Fernando, and Adrian David Cheok. 2013. Ambi kraf byobu: Merging technology with traditional craft. *Interacting with Computers* 25, 2 (2013), 173–182. DOI: http://dx.doi.org/10.1093/iwc/iws013

33. Majken K Rasmussen, Esben W Pedersen, Marianne G Petersen, and Kasper Hornbæk. 2012. Shape-Changing Interfaces: A Review of the Design Space and Open Research Questions. In *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems (CHI'12)*. Austin, Texas, 735–744. DOI: http://dx.doi.org/10.1145/2207676.2207781

34. Mark Selby and David Kirk. 2015. Experiential Manufacturing: The Earthquake Shelf. In *RTD2015*. Cambridge, UK, 25–27. DOI: http://dx.doi.org/10.6084/m9.figshare.1327994

35. Miriam Sturdee, John Hardy, Nick Dunn, and Jason Alexander. 2015. A Public Ideation of Shape-Changing Applications. In *Proceedings of the International Conference on Interactive Tabletops and Surfaces (ITS'15)*. Madeira, Portugal, 219–228. DOI: http://dx.doi.org/10.1145/2817721.2817734

36. Sarah Taylor and Sara Robertson. 2014. Digital Lace: A Collision of Responsive Technologies. In *Proceedings of the 2014 ACM International Symposium on Wearable Computers (ISWC'14 Adjunct)*. New York: ACM, 93–97. DOI:http://dx.doi.org/10.1145/2641248.2641280

37. Kentaro Ueda, Tsutomu Terada, and Masahiko Tsukamoto. 2016. Input Interface Using Wrinkles on Clothes. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers (ISWC'16)*. Heidelberg, Germany, 56–57. DOI: http://dx.doi.org/10.1145/2971763.2971782

38. Roel Vertegaal and Ivan Poupyrev. 2008. Organic User Interfaces. *Commun. ACM* 51, 6 (2008), 26. DOI: http://dx.doi.org/10.1145/1349026.1349033

39. Luke Vink, Viirj Kan, Ken Nakagaki, Daniel Leithinger, Sean Follmer, Philipp Schoessler, Amit Zoran, and Hiroshi Ishii. 2015. TRANSFORM as Adaptive and Dynamic Furniture. In *Proceedings of CHI EA '15*. Seoul, Korea, 183–183. DOI: http://dx.doi.org/10.1145/2702613.2732494