Chapter 27

Designed for Delight: Surprising Visual-Tactile Experiences Using 3D Printing in Lighting Design

Edgar R. Rodríguez Ramírez,
Sebastien Voerman and Helen Andreae

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71177

Abstract

Designing for surprise is a useful tool for designers and can elevate a product from mundane to memorable, drawing attention and inviting engagement. Existing strategies have explored surprise in product design through the exploration of sensory incongruities, most notably visual-tactile incongruities: when an object looks different to what it feels like to touch. There are two digital technologies that offer new opportunities to investigate surprise in tangible-embedded interactive systems: 3D printing and tangible interaction through sensor controls. Research is yet to investigate how visually tactually incongruous 3D printing can offer new strategies for eliciting surprise in lighting design through tangible-embedded interactive systems. This research addresses this identified gap by assessing the applicability of the Ludden's strategies to surprise through 3D printing. This was performed through the design of a series of experimental 3D printed objects and lights that sought to surprise by using visual-tactile incongruities. We suggest new approaches expressed through the final designs of four interactive lights; objects designed to inspire delight through their unique interactions and surprising qualities. We report on new strategies to surprise by using an experiential gap between vision and touch through 3D printing and we report the findings from user-testing sessions.

Keywords: surprise, visual-tactile incongruity, 3D printing, interaction design, lighting design

1. Introduction

Surprise represents a useful and powerful tool for product designers looking to inject more dynamism and intrigue into people's relationships with their objects [1–5]. It has the potential to draw people in; inviting touch and encouraging interaction. One technique for exploring surprise in the design of objects is by manipulating the user’s visual perception of the tactile experience they expect to have. This is known as a visual-tactile incongruity (VTI). The use of this was identified by Ludden [2] as a technique employed by designers to elicit surprise in their products. Ludden developed a collection of strategies that addressed and identified the various ways in which VTIs had been employed in a collection of products. Most of these products did not explore multimaterial 3D printing, which is an advanced additive manufacturing technology and offers capabilities and qualities outside the possibilities of other manufacturing techniques [6].

This chapter explores how the unique qualities that multimaterial 3D printing offers can be coupled with the capabilities of electronic sensors to generate surprising interactive technologies that create a perceptual and experiential gap, seeking to ascertain whether there is the potential for developing new specific approaches for generating surprise.

Fox-Derwin [7] identified that surprise generated through a VTI in existing products is often marred by a lack of longevity, a property that she called a “one-liner” (p. 2), also referred to as a “one-time experience” [2, 8]. Since surprise can be perceived as value-adding, this loss of surprise could be translated to a loss of perceived value in the product. Fox-Derwin [7] suggests the use of layering surprise into the interaction as a way of extending the experience and encouraging a rich reflection and relationship with the object. This research explores this in combination with VTIs and interactive systems in lighting design, seeking to extend and expand the user's’ experience and sense of surprise. Lighting design acts as a focal point, offering direction and a specific outcome for both the interaction and the surprise. This directed focus and expectation of illumination offer a specific field of design opportunities to experiment with the use of VTIs in combination with interactive systems and 3D printing.

2. Background

The key existing explorations that underpinned the research included the Ludden’s strategies for surprise that she developed by assessing existing product designs. These strategies were conceived and analyzed in the context of traditional manufacturing technologies and were limited to the prevailing manufacturing technologies that the designers had access to. Rapid prototyping technologies, particularly 3D printing, were not as widely used by designers in 2008 as they are today. Strategies proposed by Ludden explored how VTIs had been used in the studied designed objects but did not systematically explore how new and emerging technologies could have an impact on the way these strategies could be applied. Therefore, there was an opportunity to assess the applicability of these strategies to 3D printing as well as suggesting new approaches to generating surprise in product design. Polyjet photopolymerization (PPP), a multimaterial printing technology where ultraviolet light cures incremental layers of photopolymers laid down by an extrusion head, was chosen as the primary printing technology due to its capabilities for hard and soft material blending (gradients, interlocking sections, and materials within other materials) and high-resolution finishing, potentially lending itself well to setting up visual-tactile incongruities.

Ludden [2] identified six strategies for eliciting surprise in the design of a product: “new material with unknown characteristics; new material that looks like familiar material; new appearance for known product or material; combination with transparent material; hidden material characteristics; and visual illusion” (p. 31). These six strategies are all framed within two categories: Hidden and Visible Novelty. These categories illustrate an overarching difference between the strategies and whether the user can discern a visible novelty. This distinction affects the reveal of the surprise, and research [1] suggests that superficially it seems possible that a “Hidden Novelty” (HN) strategy could elicit a stronger sense of surprise due to the lack of an expectation of novelty (p. 31). “Visible Novelty” (VN) strategies explore a different angle on surprise, where the user enters the experience with a larger degree of uncertainty. While it appears that on the surface, an HN strategy might be more successful at providing immediate surprise, a VN strategy could potentially have a longer lasting effect of delight, which research corroborated by saying “people often viewed VN products as more interesting than HN products” [1].

In lighting design, most familiar systems generally favor two types of controls: on/off switches and dials (generally used for dimming light). These are the physical components that people interact with through their sense of touch and offer an opportunity for eliciting VTIs. By offering a different tactile sensation to the one visually apparent, this could layer the surprise directly into the interactive system. As a result, “the beneficial aspects of eliciting surprise through interactions with products will have the potential to be prolonged” [7]. Touch is responsible for a lot of our emotional investigation and investment, as well as our bodily awareness [9, 10]. As a result, this surprising reveal could have a greater emotional impact than if it were revealed through another sense.

There are a variety of sensors that can interpret tactile interactions, including flex sensors, capacitive touch sensors, potentiometers, pressure sensors, knock sensors, and many others. These sensors can each facilitate different aspects of tactile interaction. Pleasurable tactile interaction with products has been connected with usability [11, 12]. Ross and Wensveen [12] explored interactive product behavior, suggesting that the interactions with a product are of significant importance and should underpin the entire process of designing the product. These understandings provide a clear opportunity to emotionally and experientially extend these interactions with electronic systems and to enhance the experience and engagement with the interactive system.

3. Methods

Exploring how the unique qualities that 3D printing offers could generate surprise involved a two-phase process. Phase 1 investigated and critiqued the Ludden’s strategies through an iterative research, through design process [13] and through developing sets of criteria. These criteria formed the basis for a morphological analysis [14] that was used to develop 23 physical experiments. These experiments were all designed in the constraints of the Ludden’s strategies, with five experiments being developed for each of the three Hidden Novelty strategies and two experiments for each of the four Visible Novelty strategies. More experiments were developed for the HN strategies, as these appeared to offer more opportunities to distinctly experiment with the capacity of PPP multimaterial printing to elicit a VTI. Designed to incorporate all the distinct material qualities (soft, hard, gradients between soft and hard, transparent, opaque, translucent) available through PPP, the 23 experiments explored the visual and tactile perception of two sets of opposing visible material qualities: "softness to hardness," and "texture to smoothness" (**Figure 1**).

All 23 initial experiments were tested with 10 participants who were unfamiliar with PPP. The participants, between 17 and 20 years old, were first-year design University students, of which half of the participants were male and half were female. While they were aware of 3D printing technologies and had worked on projects by using Fusion Deposition Modeling (FDM) technologies, they had not seen or worked on PPP or other multimaterial 3D printing technology. Data were collected following a procedure similar to Evaluative Research or Product Testing [15], while also using observation and self-reporting techniques, including questionnaires [16], the Geneva Wheel of Emotions [17], and interviews [18]. Participants were shown the cubes one by one and asked to visually assess the object on scales of "hard to soft" and "textured to smooth" as well as verbally voicing their thoughts on the object through Thinking Out Loud (TOL). They were then asked to physically interact with the object and fill out the same scales again in order to gauge their tactile perception of the objects. A large difference between their visual and tactile self-reports would indicate the presence of a VTI. The participants were also encouraged to expand on their emotional experiences with the objects through the use of a customized Geneva Wheel of Emotions [17] that included segments added for "Negative-" and "Positive Surprise." Phase 1 concluded on four specific approaches to elicit VTI that were further investigated in Phase 2.

Phase 2 explored designing an individual light for each of the identified four approaches, as well as incorporating design elements from the experiments in Phase 1. The experiments from Phase 1 also informed the usage of PPP's unique qualities to develop the control mechanisms and the light-diffusing components of the lights. The lights and their corresponding interactions were designed based on qualities and features seen in the experiments from Phase 1, and the integration of sensors and microcontrollers was considered based on the specific interaction desired. The employment of the sensors and the coding around them allowed for carefully calibrated and tested interactions that highlighted and facilitated particular approaches to actually engage with the lights. All the final designs incorporated layered surprise and interaction (visual, tactile, and hidden) in order to increase engagement and delight when experiencing the object. The interactions were often hidden, encouraging users to explore, contemplate, and experiment with different ways to turn the lights on.

These lights were tested using a similar, but improved testing process from the first phase. The lights were hidden from the user before being exposed, whereupon the user had to record their visual perceptions of the object before getting to touch it. After getting to physically interact with the prototype, the user was asked to record their resultant tactile experiences of the object, as well as filling out a Geneva Wheel of Emotions in order to self-report their emotional experiences with the lights. The order of the reveal of the lights was randomized between participants, only one light was ever shown at once, and the lights were again tested with 10 participants.

Figure 1. Resulting designs from the initial experimental approach to explore freely the opportunities PPP offers to elicit visual-tactile incongruities (see **Table 1** for names and description).

4. Results

Analyzing the data from Phase 1 highlighted that certain concepts and their strategies for creating VTIs were more successful and more emotionally well received than others. This enabled the development of four approaches tailored toward eliciting surprise through the use of PPP, adapted from the Ludden's strategies:

> "Visually referencing recognizable forms, objects and structures, but making them tactually different."
>
> "Using material variances and unfamiliar forms to encourage interaction."
>
> "Suggesting surfaces have texture when they are actually smooth, through the use of an illusion."
>
> "Using internal structures to challenge the initial visual perception of the material properties." (**Tables 1–3**).

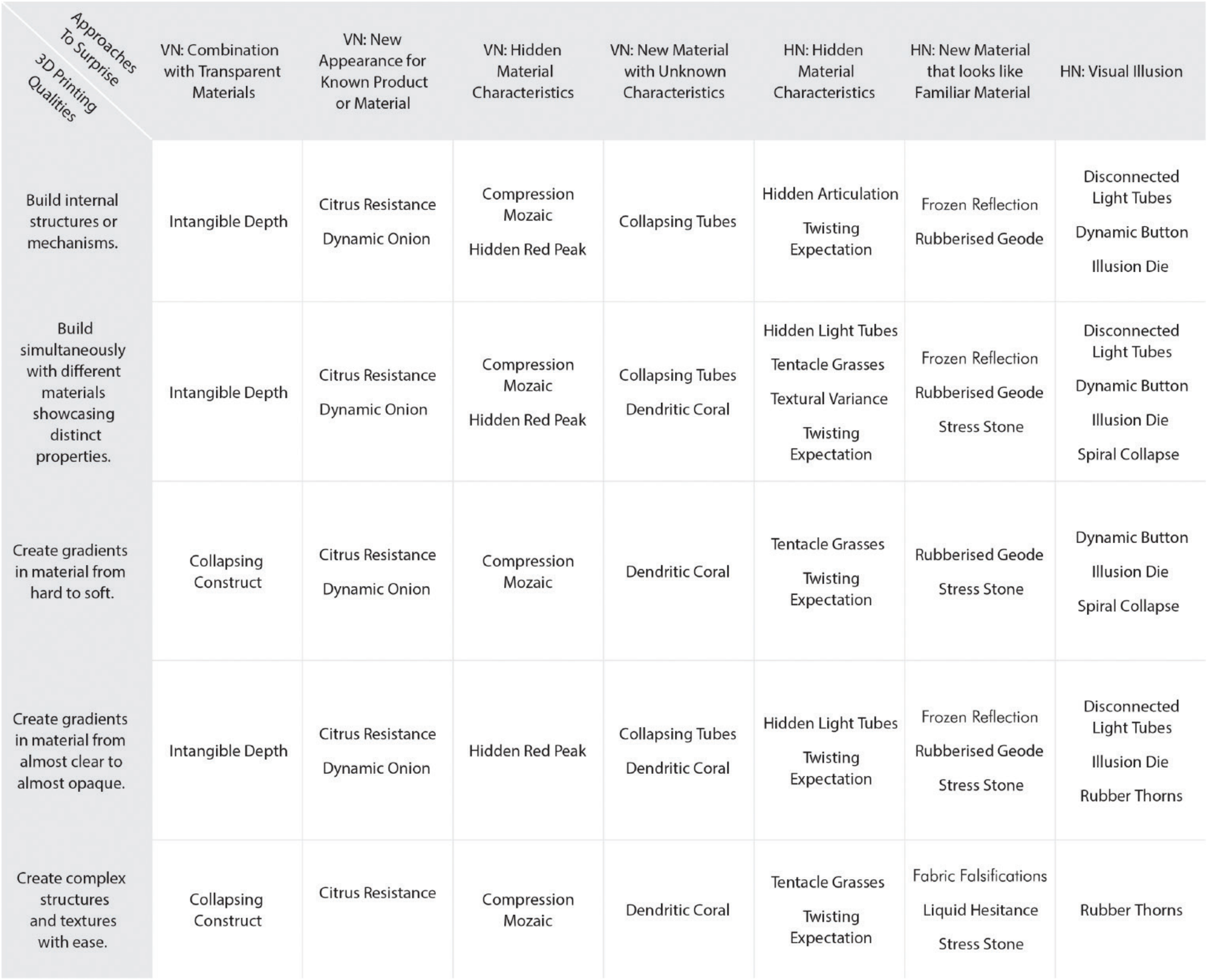
Each of the final four lights incorporated a very different interaction, with some leaning more heavily on the coding of the microcontrollers, whereas others relied primarily on the sensors. All the lights incorporated a "reveal" aspect with the activation of the light. There is no obvious "switch" on any of the lights, so users had to experiment with the lights to discover the activation. The design of the lights (**Figure 2**) incorporated various elements that were designed to elicit VTIs, all built directly into the means of activating the lights. Each of these lights was designed as an expression of one of the four approaches identified at the end of Phase 1.

Design one (**Figure 3**) was based off a crystalline structure, using this recognizable structure as a basis for creating a VTI where the structure was revealed to be soft on touch. This reveal of the soft structure also showed the user what the interaction was; by flexing each crystal individually, the bend sensors within would allow the user to tune the amount of light emanating from the base of each crystal. A series of carefully calibrated sensors and coded responses allowed the individual an intuitive control of the lights. This design explored the potential of the "Visually referencing recognizable forms, objects, and structures, but making them tactually different" approach. The 3D printed structure made use of the advanced material composition possible with PPP, with fine blending between the softest materials at the tips and a rigid structure at the base to keep the crystal structures in place. The design also included an internal semi-flexible skeleton as well as a procedurally generated series of minuscule opaque volumes to simulate occlusions and sharp-looking edges in an attempt to carefully replicate the visual appearance of a crystal. This VTI proved to be the most surprising out of all the designs, as the visual reference was the most well understood, and a clearly visually rigid quality was being challenged with a malleable, soft, and tactile structure.

Design two (**Figure 4**) relied on the user's exploratory curiosity, hiding six different switches under the myriad of soft, organic forms that yielded to the touch. The forms, each a series of intersecting 3D volumes of various densities and rigidities, were parametrically developed to incorporate small variances between each other, emulating variety between the individuals of

①	*Intangible Depth*	Used an under-the-surface gradient in PPP materials to alter depth perception of a seemingly transparent material.
②	*Collapsing Construct*	Used a textured cavity to create the look of a filled centre, which readily collapsed when touched.
③	*Citrus Resistance*	Used variance in PPP material to create a squishable and heavily tactile form referencing a citrus fruit.
④	*Dynamic Onion*	Used intense layering of PPP materials to achieve an onion-like object with variations in material properties.
⑤	*Compression Mosaic*	Hid soft material structures underneath harder components, in order to create a flexible hard surface.
⑥	*Hidden Red Peak*	Hid a disjointed series of pieces that form an image when viewed from a specific angle.
⑦	*Collapsing Tubes*	Created a structure that does not make an explicit reference to anything specific, and makes use of soft PPP materials to collapse in a bizarre way.
⑧	*Dendritic Coral*	Created a reference to coral-like structures, a structure that most people do not get to touch, only look at. Make object that is soft with hard detailing.
⑨	*Hidden Articulation*	Object was designed to explore the potential of internal mechanisms and explosive motion.
⑩	*Hidden Light Tubes*	Created a cube that uses clear PPP material to allow light to pass through the model in unexpected locations.
⑪	*Tentacle Grasses*	Explored the potential of the PPP material blending in order to create an intense tactile experience.
⑫	*Textural Variance*	Explored the ability to suggest softness where there is rigidity, by layering the softer PPP materials over a hard core.
⑬	*Twisting Expections*	Created an object that translated an inputted twisting motion into a sudden expanding motion, through PPP material variance.
⑭	*Fabric Falsification*	Used hard materials and intense texturing from fabric simulations in order to visually suggest softness and familiarity.
⑮	*Frozen Reflection*	Created a structure using PPP printing that looks very similar to an ice cube but ends up being soft and warm.
⑯	*Liquid Hesitance*	Explored the potential making printing look like a thick, pasty liquid, attempting familiarity.
⑰	*Rubberised Geode*	Referenced crystal structures through the form as well as the optical quality of PPP. The crystalline structure is actually soft.
⑱	*Stress Stone*	Explored making soft PPP material variants look like stone. Explicitly explored form as well as surface texture.
⑲	*Disconnected Light Tubes*	Created a cube with light tubes that are connected in abnormal ways, encouraging curiosity and exploration.
⑳	*Dynamic Button*	Created a single moving structure using PPP that reveals new components when a button is pressed.
㉑	*Illusion Die*	Explored the possibility of different points of view revealing different symbols to the user.
㉒	*Rubberised Thorns*	Created a cube that references hard, dangerous forms and have them revealed to be soft and pleasant.
㉓	*Spiral Collapse*	Created a form that looks like a solid textured cube, but that is actually revealed to be a dynamic and smooth spiralling structure.

Table 1. Name and description of the 3D printed design experiments from Design Phase 1 (see **Figure 1** for photos of each experiment).

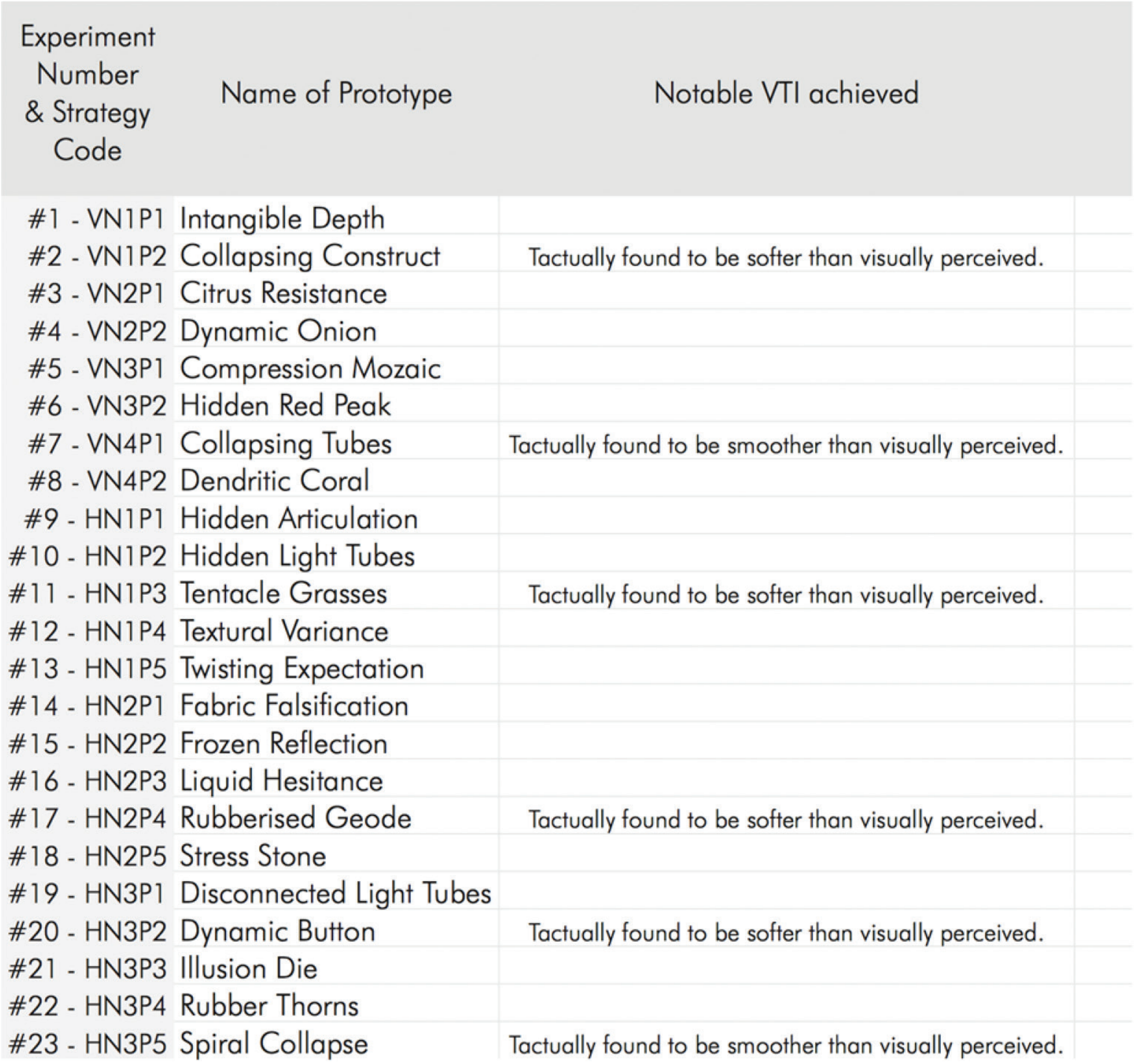


Approaches To Surprise / 3D Printing Qualities	VN: Combination with Transparent Materials	VN: New Appearance for Known Product or Material	VN: Hidden Material Characteristics	VN: New Material with Unknown Characteristics	HN: Hidden Material Characteristics	HN: New Material that looks like Familiar Material	HN: Visual Illusion
Build internal structures or mechanisms.	Intangible Depth	Citrus Resistance Dynamic Onion	Compression Mozaic Hidden Red Peak	Collapsing Tubes	Hidden Articulation Twisting Expectation	Frozen Reflection Rubberised Geode	Disconnected Light Tubes Dynamic Button Illusion Die
Build simultaneously with different materials showcasing distinct properties.	Intangible Depth	Citrus Resistance Dynamic Onion	Compression Mozaic Hidden Red Peak	Collapsing Tubes Dendritic Coral	Hidden Light Tubes Tentacle Grasses Textural Variance Twisting Expectation	Frozen Reflection Rubberised Geode Stress Stone	Disconnected Light Tubes Dynamic Button Illusion Die Spiral Collapse
Create gradients in material from hard to soft.	Collapsing Construct	Citrus Resistance Dynamic Onion	Compression Mozaic	Dendritic Coral	Tentacle Grasses Twisting Expectation	Rubberised Geode Stress Stone	Dynamic Button Illusion Die Spiral Collapse
Create gradients in material from almost clear to almost opaque.	Intangible Depth	Citrus Resistance Dynamic Onion	Hidden Red Peak	Collapsing Tubes Dendritic Coral	Hidden Light Tubes Twisting Expectation	Frozen Reflection Rubberised Geode Stress Stone	Disconnected Light Tubes Illusion Die Rubber Thorns
Create complex structures and textures with ease.	Collapsing Construct	Citrus Resistance	Compression Mozaic	Dendritic Coral	Tentacle Grasses Twisting Expectation	Fabric Falsifications Liquid Hesitance Stress Stone	Rubber Thorns

Table 2. Design Phase 1: 3D printing qualities that PPP affords and how the strategies to surprise were applied.

a species as well as creating a less homogeneous surface to interact with. Each switch activated a separate panel of light under the structure, and the organic formation created a unique diffusion of the light. This design explored the "Using material variances and unfamiliar forms to encourage interaction" approach. The two halves of the form spun independently of one another, ensuring that the user would be unlikely to be able to memorize the location of the switches, refreshing the search for the switches between uses. This design proved to be frustrating for a number of participants, as the organic structures proved too numerous to be able to reliably find a switch in a short time frame.

Design three (**Figure 5**) built the interaction around the relation of shapes and the "Suggesting surfaces have texture when they are actually smooth, through the use of an illusion" approach. The 3D printed structure needed to be stretched and attached to the other half of the form to light up. The VTI emerged out of the sinuous "slinky-like" form of the 3D printed component, which is not apparent until it is touched. When the structure is stretched and attached to the other half of the design, a sensor detects the magnetic field created by a small magnet in the end of the 3D printed component, and the structure lights up through LEDs built into the base of the wooden structure. A number of participants experienced an "Aha" moment when they



Experiment Number & Strategy Code	Name of Prototype	Notable VTI achieved
#1 - VN1P1	Intangible Depth	
#2 - VN1P2	Collapsing Construct	Tactually found to be softer than visually perceived.
#3 - VN2P1	Citrus Resistance	
#4 - VN2P2	Dynamic Onion	
#5 - VN3P1	Compression Mozaic	
#6 - VN3P2	Hidden Red Peak	
#7 - VN4P1	Collapsing Tubes	Tactually found to be smoother than visually perceived.
#8 - VN4P2	Dendritic Coral	
#9 - HN1P1	Hidden Articulation	
#10 - HN1P2	Hidden Light Tubes	
#11 - HN1P3	Tentacle Grasses	Tactually found to be softer than visually perceived.
#12 - HN1P4	Textural Variance	
#13 - HN1P5	Twisting Expectation	
#14 - HN2P1	Fabric Falsification	
#15 - HN2P2	Frozen Reflection	
#16 - HN2P3	Liquid Hesitance	
#17 - HN2P4	Rubberised Geode	Tactually found to be softer than visually perceived.
#18 - HN2P5	Stress Stone	
#19 - HN3P1	Disconnected Light Tubes	
#20 - HN3P2	Dynamic Button	Tactually found to be softer than visually perceived.
#21 - HN3P3	Illusion Die	
#22 - HN3P4	Rubber Thorns	
#23 - HN3P5	Spiral Collapse	Tactually found to be smoother than visually perceived.

Table 3. Notable VTIs achieved by the initial experiments.

understood the intended interaction but were all surprised by the emergent light quality that highlighted some less visible details of the design, such as the pattern of miniature translucent volumes inside the slinky-like component.

Design four (**Figure 6**) references a dial-like structure, which however has collapsible sections, which cave inwards when gripped tightly, showcasing this design "Using internal structures to challenge the initial visual perception of the material properties approach. The dial is a potentiometer that can be turned to cycle up through all the light combinations; however, these emerge in an interesting way, using a four-way binary coding system, which was linked to four physical relays, allowing a gradual "mechanical dimming" through the individual cycling of differently numbered groups of lights. The interaction here was rewarding and delightful, incorporating an auditory component as well through the opening and closing of the relays, with the reveal of light patterns being particularly praised by research participants. However, the reveal of the collapsible structure was not noticed by a number of the participants.

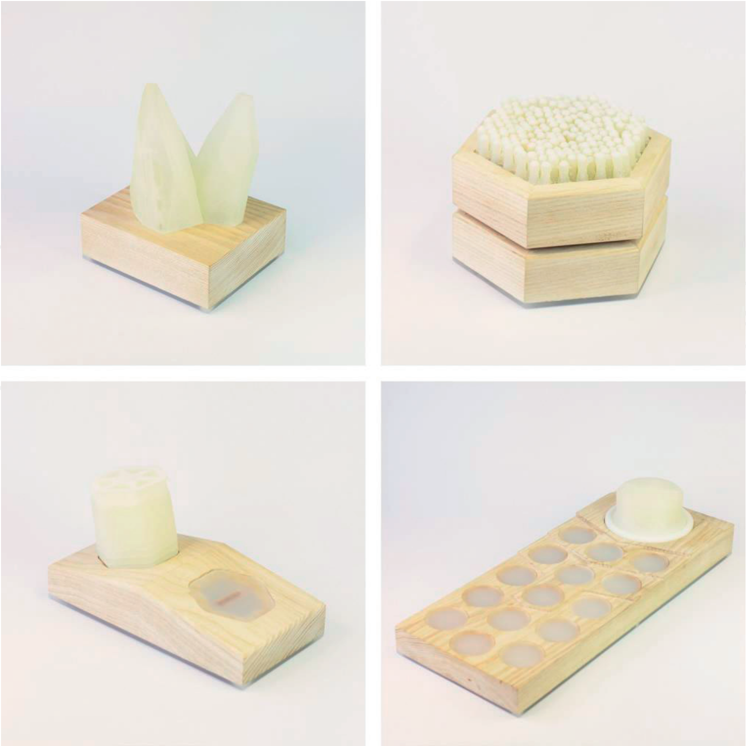


Figure 2. (Clockwise from top left): design one: malleable structures; design two: organic formation; design four: rotary relays; design three: spiral connection.

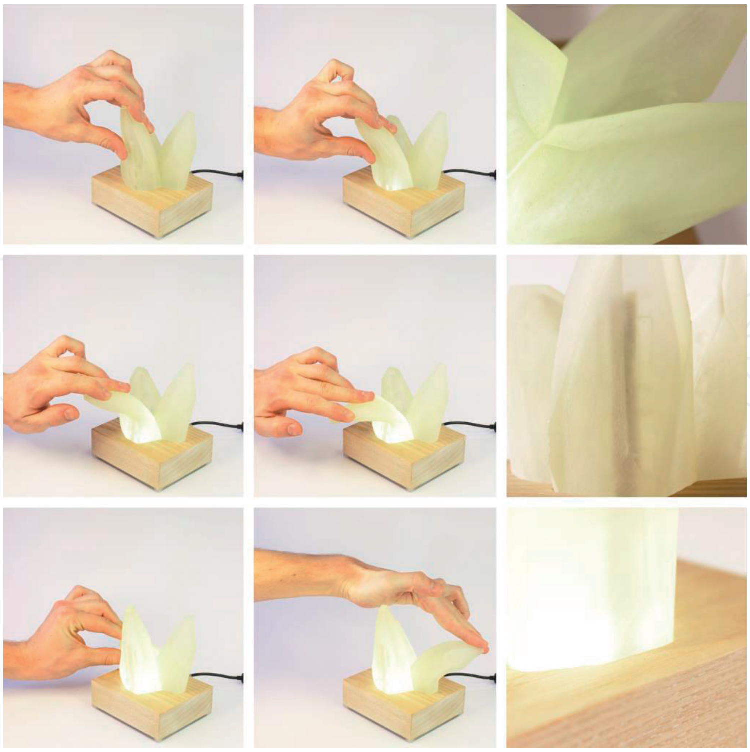


Figure 3. Design one: malleable structures. PPP 3D print, wood, Arduino microcontroller, flex sensor, and LED lights.

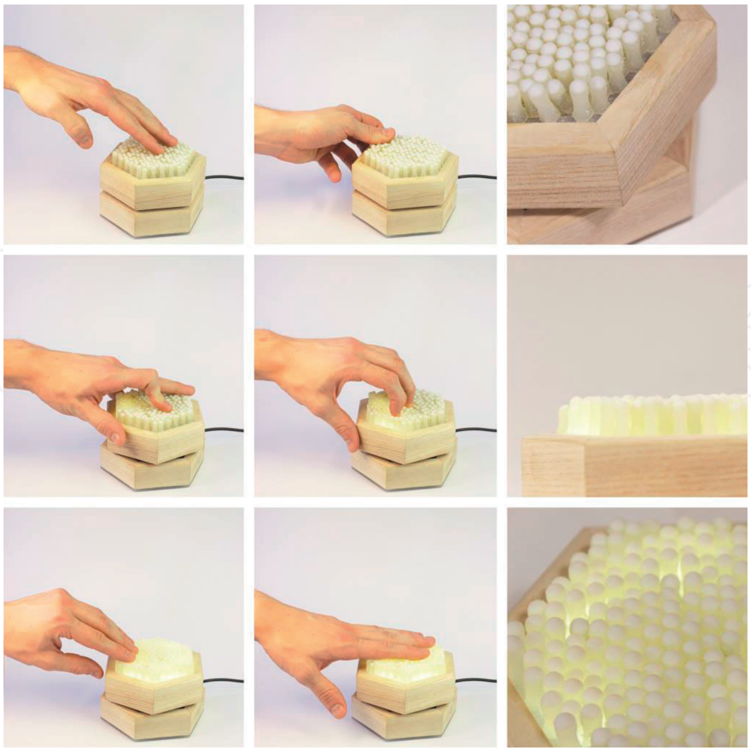


Figure 4. Design two: organic formation. PPP 3D print, wood, Arduino microcontroller, switches, and LED lights.

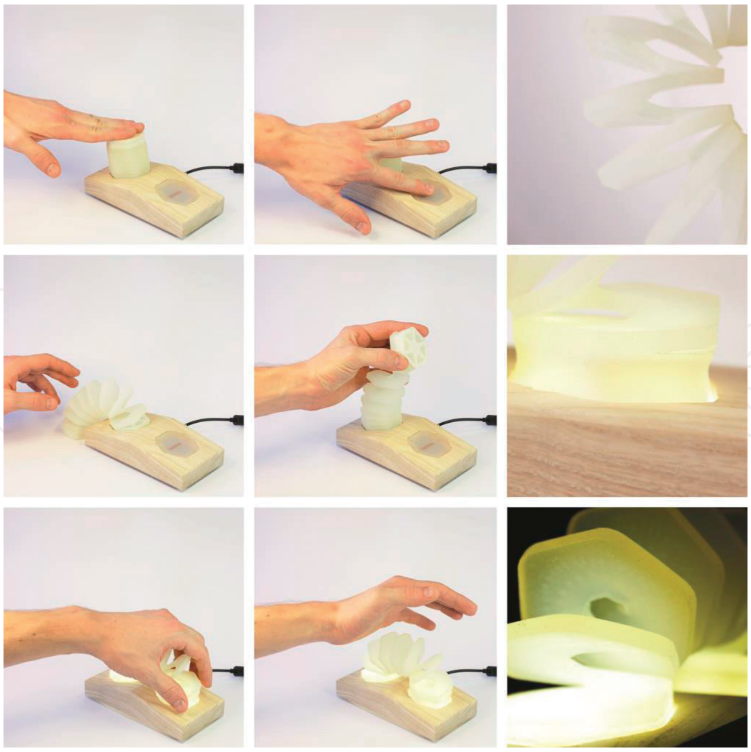


Figure 5. Design three: spiral connection. PPP 3D print, wood, Arduino microcontroller, magnetic sensor, and LED lights.

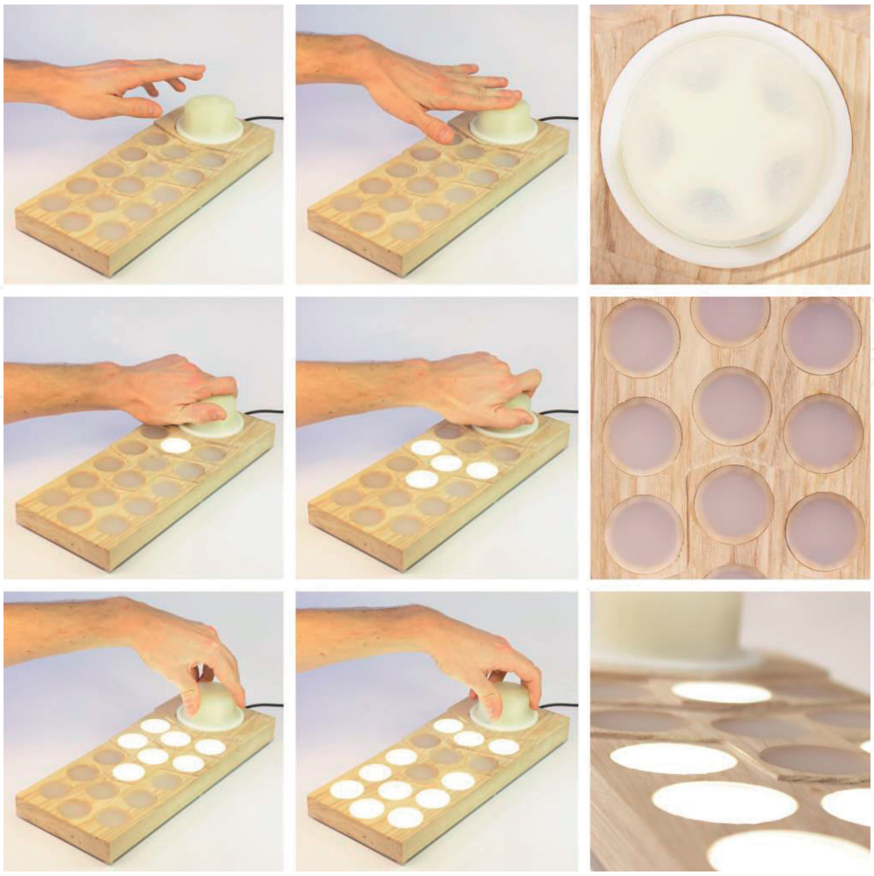


Figure 6. Design four: rotary relays. PPP 3D print, wood, Arduino microcontroller, potentiometer, and LED lights.

5. Discussion

Ludden developed strategies through looking at existing products that evoked surprise; yet there was only one example of a product employing 3D printing, namely the "Konko Lamp," designed by Willeke Evenhuis & Alex Gabriel. Exploring the possibility of using PPP 3D printing to elicit surprise through the use of VTIs, particularly using its capabilities to print in soft and hard material combinations, yielded interesting findings that suggested 3D printing appears to show a greater usefulness for the '*Visible Novelty*' (VN) subset of the Ludden's strategies, as the designs based around these strategies tended to invite interaction and speculation.

After conducting research into the applicability of these strategies, it would appear that some of her strategies do offer viable angles for exploring surprise through the use of 3D printing. However, given the still somewhat limited visual qualities of PPP printing at present, achieving effective expressions of Ludden's '*Hidden Novelty*' (HN) strategies is still out of reach. Ludden et al. highlighted that the "HN surprise type includes products that seem familiar to the perceiver, but have unexpected tactual properties" (p. 30). While this appears to sound like the effect seen in the prototype *Malleable Structures*, participants still mentioned that "*It looks odd*" (Participant 8) and "*It looks like a crystal, but I'm not sure*" (Participant 2). A number of participants made comments suggesting that they were not convinced about their visual perceptions, suggesting a more predominant presence of VN in the designs, despite the best efforts to truthfully emulate the real qualities of the desired structure. Finding materials that PPP can specifically emulate, and designing familiar forms and structures around those could address achieving true HN designs.

We believe this primarily due to the "look" of PPP 3D printing. Many participants picked up on the visual strangeness of the materials (most of the prototypes ended up looking somewhat like complex arrangements of various kinds of candle wax). Based on their responses, it simply does not appear to have been possible to fully deceive the viewer's perception enough to make them believe the materials they see are not "odd." However, having a fundamental understanding of the qualities and possibilities of PPP can still offer designers specific ways to elicit surprise. Ludden et al. [2] noted that "people tended to exhibit more exploratory behaviors when interacting with VN products."

People often viewed VN products as more interesting than HN products" (p. 37). For the designs developed in Phase 2; which all incorporated aspects of VN, almost all participants spent well over a minute exploring most of the lights. The reverse of this was seen in several of the purely HN strategy cuboid prototypes from Phase 1, which usually elicited only very brief interactions and comments such as "Oh, it's just hard. That's disappointing." (Participant 4).

Ludden's strategies in the HN category were still essential to the development of the final designs, but the final light designs themselves actually end up fitting predominantly into the VN category, due to the inherent inability for PPP to accurately simulate the visual qualities of other recognizable materials. The four designs developed in Phase 2 explored combining specific PPP capabilities with the Ludden's [2] strategies. The approaches put forward are based on a systematic exploration through the Research through Design approach, as well as the questionnaires and interviews employed during the user testing. These approaches are not exhaustive, and there is potential for research to develop further approaches related more specifically to other 3D printing technologies beyond PPP.

3D printing is an incredibly important growth area presently, with the latest Wohlers Report highlighting that "the 3D printing industry has grown by US$1 billion" [19]. Understanding the state of the art, what can be done with the technologies, as well as how it can be pushed to the limits is vital in ensuring designs utilizing it can remain surprising. Surprise has, as discussed in previous sections of this chapter, a lot to offer to designers. Exploring the potential of 3D printing, how it can surprise and challenge our sensory perception through the use of VTIs is a topical, relevant exposition. Its application to the comprehensible field of lighting design is one particular angle that this chapter pursued. There is a myriad of other areas dependent on interesting, engaging interactions that this research could potentially inform.

6. Conclusion

Designed for Delight sought to expand on existing strategies for the elicitation of surprise to include the new, advanced manufacturing technique of 3D printing. The strategies, suggested by Ludden [2], were based around visual-tactile incongruities. This chapter systematically explored and critiqued the possibility of applying these strategies to the 3D printing technology Polyjet photopolymerization (PPP), using this to then generate new and specific approaches. This was achieved through designed objects exploring all the Ludden's [2] strategies, and these approaches then inform the design of lights that incorporated interactive controls imbued with VTIs. The exploration of lighting design was chosen due to the expectation of illumination from the interaction. This offered the opportunity to counter expectations of the interaction as well as the reveal of light.

Upon reflection over the data from user testing and the resultant developed lights, it was realized that a key determinant for the success of these approaches in these contexts was how well the approach for eliciting a VTI was combined with the interaction designed for the lights. The importance of this marriage between the approach, the interaction and the possibilities of the 3D printing technology cannot be overstated in this context. In order to generate surprise through a VTI, the designer needs to clearly comprehend their chosen 3D printing technology. This requires a display of sensitivity toward the qualities achievable and carefully employing the desired approach. This will allow designers to craft products that can surprise and delight, conveying more meaning and allowing the end-users to build better person-product relations.

Acknowledgements

This chapter is part of a Masters project in industrial design [20].

Author details

Edgar R. Rodríguez Ramírez*, Sebastien Voerman and Helen Andreae

*Address all correspondence to: edgar.rodriguez@vuw.ac.nz

Victoria University of Wellington, Wellington, New Zealand

References

[1] Ludden G, Schifferstein H, Hekkert P. Surprise as a design strategy. Design Issues. 2008; **24**(2):28-38

[2] Ludden G. Sensory incongruity and surprise in product design [Internet] [Doctoral dissertation]. Delft: Technical University of Delft, Faculty of Industrial Design Engineering; 2008 [cited 2009 Jan 11]. Available from: http://repository.tudelft.nl/view/ir/uuid%3A8cafddd5-6a38-42e4-9ca7-62abb4bfcaab/

[3] Rodríguez Ramírez ER. The role of surprise on persuasion in industrial design. International Journal of Product Development. 2012;**16**(3/4):263-283

[4] Rodríguez Ramírez ER. Elements of Surprise: Industrial Designers' Strategies for Eliciting Surprise Through Interaction. Wellington: Victoria University of Wellington; 2011

[5] Rodríguez Ramírez ER. Industrial design strategies for eliciting surprise. Design Studies. 2014 May;**35**(3):273-297

[6] Chua CK, Leong KF. 3D printing and additive manufacturing: Principles and applications. 2017.

[7] Fox-Derwin E. White lies: Visual-tactile sensory incongruity and surprise within the product-skin [Internet] [Masters dissertation]. Wellington: Victoria University of Wellington, School of Design; 2011 Available from: http://victoria.lconz.ac.nz/vwebv/holdingsInfo?bibId=1548631

[8] Desmet PMA. Measuring emotion: Development and application of an instrument to measure emotional responses to products. In: Blythe M, Overbeeke K, Monk AF, Wright PC, editors. Funology: From Usability to Enjoyment. Dordrecht, Boston: Kluwer Academic Publishers; 2004. p. 111-124 (Human-Computer Interaction)

[9] Sachs F. The intimate sense. The Sciences. 1988 Jan 2;**28**(1):28-34

[10] Scott M. Tactual Perception. Australasian Journal of Philosophy. 2001 Jun 1;**79**(2):149-160

[11] Jordan PW. Designing Pleasurable Products: An Introduction to the New Human Factors. London: Taylor & Francis; 2000.

[12] Ross PR, Wensveen SAG. Designing behavior in interaction: Using aesthetic experience as a mechanism for design. International Journal of Design. 2010;**4**(2):3-13

[13] Burdick A. Design (as) research. In: Design Research: Methods and Perspectives. Cambridge: MIT Press; 2003

[14] Zwicky F. The morphological approach to discovery, invention, research and construction. In: New Methods of Thought and Procedure. Heidelberg, Germany: Springer Berlin Heidelberg; 1967. 273-197

[15] Kittur A, Chi EH, Suh B. Crowdsourcing user studies with Mechanical Turk. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM; 2008 April; 453-456

[16] Robson C, McCartan K. Real World Research. 4th ed. Hoboken: Wiley; 2016

[17] Scherer KR. What are emotions? And How can they be measured? Social Science Information. 2005;**44**(4):695-729

[18] Goodman E, Kuniavsky M, Moed A. Observing the User Experience: A Practitioner's Guide to User Research [Internet]. Burlington, MA: Elsevier Science; 2012 [cited 2017 Mar 7] Available from: http://public.eblib.com/choice/publicfullrecord.aspx?p=978450

[19] Wohlers T. Wohlers Report 2016. Wohlers Associates Inc.; 2016

[20] Voerman S. Designed for Delight: Surprising Visual-Tactile Experiences Using 3D printing in Lighting Design. Wellington: Victoria University of Wellington; 2016