ShapeCanvas: An Exploration of Shape-Changing Content Generation by Members of the Public

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ABSTRACT
Shape-changing displays - visual output surfaces with physically-reconfigurable geometry - provide new challenges for content generation. Content design must incorporate visual elements, physical surface shape, react to user input, and adapt these parameters over time. The addition of the 'shape channel' significantly increases the complexity of content design, but provides a powerful platform for novel physical design, animations, and physicalizations. In this work we use ShapeCanvas, a 4×4 grid of large actuated pixels, combined with simple interactions, to explore novice user behavior and interactions for shape-change content design. We deployed ShapeCanvas in a café for two and a half days and observed users generate 21 physical animations. These were categorized into seven categories and eight directly derived from people's personal interest. This paper describes these experiences, the generated animations and provides initial insights into shape-changing content design.

Author Keywords
Shape-changing displays; Physical Animation; Content Design; User interaction.

ACM Classification Keywords
H.5.2. User Interfaces: Graphical User Interfaces, Input devices and strategies, Interaction Styles, Screen Design.

INTRODUCTION
Shape-changing displays' physical dynamicity exploits users' rich visual and tactile senses. This new generation of displays offer an additional information channel - the physical channel - opening up a wide range of new application areas [17]. However, this additional channel comes with additional complexity in content design: visual output must now be accompanied by shape-information. As with any new 'hosting' platform, content, and therefore its

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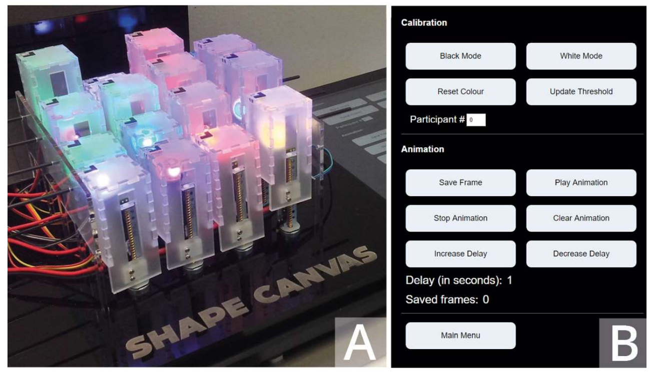

Figure 1: ShapeCanvas, a 4x4 grid of height and color actuating pixels (A) with touchscreen controls (B).

generation, will be key to its future success. However, the relative immaturity of the shape-change field currently means that content generation remains largely unexplored.

This paper therefore aims to understand how people approach and react to the task of generating content for shape-changing displays. To do this, we deployed ShapeCanvas, a 4×4 grid of large actuated pixels, into a public environment for two and a half days to observe people generating their own physical animations. Users were able to: (1) directly manipulate the height of each physical pixel with their hands, (2) control the color of each physical pixel using a simple light source, and (3) generate physical animations via key frames. We chose such a setting to understand novice user actions and reactions (rather than trained or expert users). This allows us to understand requirements for a diverse range of approaches, design choices, and potential applications.

Participants successfully generated 21 physical animations that we classified into seven categories: Landscape Modelling, Structured Recreations, Artistic Expression, Game Simulation, Physical Typography, Symbols and Signs, and Face Illustrations. We report on the generated content, interaction issues, and observations of participants' design process.

To summarize, this paper contributes: (1) ShapeCanvas, a small, but robust shape-changing display (2), a two and a half day deployment of ShapeCanvas into a public environment to understand how novices generate content (3), a thematic categorization of generated content, empirical report of interaction, and discussion on future approaches.

RELATED WORK

Shape-Changing Displays

Shape-changing displays dynamically change their physical form to visualize data and information. They are becoming more dynamic and scalable and can be used for both static and dynamic physical information visualizations [5, 11]. Rasmussen et al. [15] identify eight types of shape-change for interfaces. Coelho and Zigelbaum [3] surveys the design space for shape-changing materials. Poupyrev et al. [14] presents an overview of actuation styles in user interfaces, including new interaction scenarios from dynamic shapes.

An early example of a shape-changing display is FEELEX [8] which combines haptic sensations with computer graphics. The Actuated Workbench [13] is a tabletop surface with integrated object tracking, physical actuation, and projected video. Objects on the surface can be both directly manipulated as well as self-actuated. Ylirisku et al. [20] explores web-connected physical artefacts, e.g. the Manhattan prototype shows contextual data around a household using actuated blocks. Harrison and Hudson [7] developed a touchscreen interface with deformable buttons that do not require dedicated actuators or complex circuitry.

Most current explorations focus on a single application output [17-19]: this work starts to explore how we can let users generate their own content. Kinetic Tiles [10] are modular construction units for kinetic animations that use preset movements, design via animation toolkit, and direct input. The concept of frame by frame animation to freely create graphics and actuations to precisely demonstrate novice user's ideas is used in ShapeCanvas.

Interaction with Shape-Changing Displays

Shape-changing displays are still a relatively new area of exploration and the community is still building an understanding of user interaction. Current research [2, 5, 12] explores the combined use of freehand gestures and direct touch to resolve input ambiguities. Interaction with shape-changing displays is typically through gestures, direct manipulation, or direct data input through an external interface [8, 9]. Rasmussen et al. [15] also describes three approaches to shape-changing interaction: no interaction, indirect interaction, and direct interaction. It is more effective to directly interact with individual pixels using hands [18]. ShapeCanvas uses a combination of direct input, gestures, and operation through an external interface.

Eliciting User Input to Design Interaction

In this work, we look at content generation from a novice user's perspective: a technique that allows researchers to gain creative input on the design process [4] and new suggestions for designing direct interactions and gestures [19]. This technique has already been applied to the shape-change arena: by sampling a public user-base [17] new application ideas have already emerged that go beyond those documented by the research community. This shows the effectiveness of public involvement and allows researchers to compare and contrast ideas in existing literature.

SYSTEM DESIGN

ShapeCanvas (Figure 1A) is a 4x4 grid of actuators, each of which have user configurable height and color. We wished to observe 'pixel level' interaction so we kept the display size small. We augmented ShapeClips [6] with laser-cut frosted-acrylic cases, attached LDR light sensors to the top left corner to sense user interactions, and utilized ShapeClip's built-in LED for the display. Each physical pixel has a top surface area of 35×35mm, and actuates 100mm. The ShapeClips were placed onto an 18" touchscreen that, along with custom-built software, was used to control the ShapeClips, run demonstrations, and facilitate user configuration of physical animations (Figure 1B). The system automatically logged all user interactions.

Interaction Design

We designed simple interactions that allowed users to configure each physical pixel's height and color. Animation sequences were compiled using the touchscreen (Figure 1B).

Physical Pixel Height

Height control follows a 'mimic' approach (as observed by Alexander et al. [1]) using the LDR for input detection. To activate a physical pixel, the user first taps the top panel of the pixel (over the LDR). To move a pixel up, the user moves their finger vertically: the physical pixel follows. To move a pixel down, the user presses their finger on top of the physical pixel: again it follows, with the user releasing their finger when the desired height is reached.

Physical Pixel Color

We use a visual representation to control pixel color: shining a small light source (torch) onto a physical pixel triggers the built-in LED to iterate through the six secondary colors at two second intervals. Removing the light source stops rotation and the color is selected. The torch was used as a "paint brush" to maximize physical interaction.

Shape-Changing Animation

Once the height and color is configured, users can save the frame as part of an animation sequence (Figure 1B). Once multiple frames are saved, the timing between the frames can be adjusted to modify actuation speed; the system will then generate a looped animation.

USER STUDY

In order to gain initial insight into how novice users would generate physical animations using a shape-changing display we deployed the pixel canvas in a busy café. Novice users (rather than trained groups) allowed us to gain insight into initial interactions and reactions, potential content design domains, and ideas for future applications. A large display advertised the study in the café, which allowed participants to be self-selected by approaching the researcher.

Study Format

ShapeCanvas was set up in a busy café for two and a half days, and used by 21 participants. Participants were seated in front of a low table which supported ShapeCanvas. Each study was divided into three phases: (PH1) *demonstration* *phase* using a weather forecasting application with static and dynamic physical examples, (PH2) *interaction training phase* to allow users to understand the height and color controls, (PH3) *content design phase* where participants were asked to create their own physical animations.

Participant Demographics

The study consisted of 21 participants (6 females) with age ranging from 18 up to 45+ years. Occupational backgrounds ranged from Policy Adviser, Chef, Systems Developer, Barista, Chemist, and Student. In total, 18 participants had experience with graphical software but lacked experience in animation (10 participants either never used animation software or only a few times a year). The average time spent performing the study was approximately 21 minutes.

Reactions to the Demo Applications

Each participant was shown three static physical weather frames (“Clear Sky”, “Few Clouds”, and “Many Clouds”) and two motion animations (“Rain Animation”, and “Current Wind Direction”). Participants found dynamic heights a useful indicator of weather conditions. They expressed greatest interest in the wind and rain animations, with four participants wanting to see a larger, higher resolution version. Several participants put their hand on the display to feel the wind motion and said it would be a useful way for visually impaired users to have a more engaging experience. P7 stated that the dynamic height changes “adds an extra level of dimension and makes people pay more attention to it.... bringing the outside indoors”.

ShapeCanvas Application Ideas

Throughout the study participants were encouraged to think of future applications for the display [17]. A diverse range of possible application areas emerged: landscape and terrain modeling (7), dynamic board game layouts (3), modeling physical artifacts such as pizza sizes (2) or commercial products (3), displaying complex structures such as cloud formations (P3) and forest canopy layers (P15). P17 described using ShapeCanvas as a tool for modeling prototypes and products, to scale, to demonstrate physical models to overseas stakeholders. Participants pursued these ideas, along with others, during the content design phase.

Low-Level Interactions with ShapeCanvas

Participants initially performed interactions using their dominant hand (right = 16; left = 5) and one participant used their index finger for controlling height. Participants initially interacted with the pixels on the row closest to them, and reached over to the ones further back in the later stages. For single color-changes participants used the torch with their non-dominant hand; but swapped to the dominant hand to perform canvas-wide color changes. During the animation phase we noticed participants used bimanual interaction: their left hand was used to control pixel height on the left side of the display and their right hand on the right side. Figure 2 shows a summary of where canvas interactions were performed; edges and close corners were the most popular. These observations showed that participants quickly learned to efficiently use the spatial position of their body for design; however the hard-to-reach pixels received less attention.

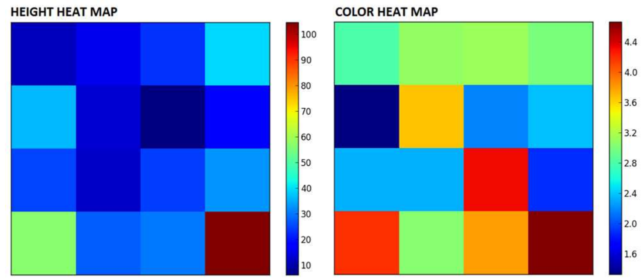

Figure 2: Height (left) and color (right) interaction density (average number of interactions per participant) heat maps.

Physical Animations

Each participant made at least one frame, with the longest animation containing 24 frames (mean: 5 frames). Interaction time varied depending on the complexity of participants’ design approach. Those who used less pixels per frame generally had shorter interaction time (e.g. P4 generated 24 frames in 9:58 minutes whereas P6 generated 6 frames in 24:31 minutes). Animations can be categorized as artistic expressions (6), structured recreations (3), physical typography (3), face illustrations (3), landscape modeling (2), symbols and signs (2), and game simulation (2). Each participant walked through their design once completed.

Artistic Expression

Six of the participants used the system for artistic expression. They explored height and color interactions of the 4×4 grid, activating individual pixels in no particular order. They used it “just for fun” (P3, P7, P14) and “just to see what happens” (P7, P8). These artistic animations ranged from 3 to 12 frames. Figure 3E is an example of a frame created by P3.

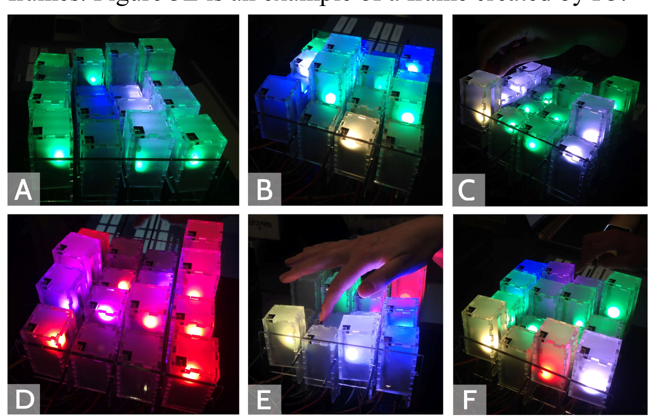

Figure 3: Assortment of animation frames created by participants. Photographs described inline.

Structured Recreations

After initial explorations three participants recreated physical environments. P2 created the “Las Vegas Strip” (2 frames). P10 visualized a rainbow effect by selecting specific colors and heights for each animation frame (8 frames). Similarly, P21 explored a physical wave pattern that changed color (14 frames), stating that the system could be applied in mathematics to “physically represent the wave equation”.

Physical Typography
Three participants created animations that spell out their name (Figure 3D showing letter "I"). Participants wanted to create content personal to them and stated that "it seems like a simple thing to show on a low resolution display" (P6).

Face Illustrations
Two participants (P13, P20) created simple "face" icons. P13 made a sad face to represent their current mood at the time (3 frames). Similarly, P20 made a "smiley face" where the mouth moved to change expression (2 frames). P17 came from an artistic background and created a detailed partial profile of a face which emerged from the display (3 frames). They used the height of each pixel to show the contours of the nose, eyebrow, and eye.

Landscape Modelling
Two of the participants used the system to create landscapes. P4 generated a terrain map (24 frames) that visualized a path (green pixels) through a set of mountains (red pixels that were raised higher which represented danger areas, Figure 3F). Their aim was to visualize suitable walking paths in mountainous areas. P15 modeled a forest canopy (2 frames) growing and dying over time (e.g. Figure 3A shows a gap in the center representing dead trees). P15 used the system to "show the forest moving over time as it is difficult to represent the patterns in 2D".

Symbols and Signs
P11 created a single frame that showed a hazard sign. They used height of the red pixels on the outside of the grid to represent how severe a hazard can be. The four pixels in the center had a range of colors that mapped to a particular threat. P5 attempted to make a "thunder" symbol.

Game Simulation
Two participants generated game simulations. P1 made a simple game for their cat (6 frames). Each pixel represented a mouse which goes up and down at random stages of the animation to attract the attention of the cat. P9 based their animation on the strategy board game "Risk" (Figure 3C). They used the grid to generate a dynamic environment for game play (6 frames). The animation simulates a plane (blue pixel) flying over the landscape (green pixels) to a target (yellow pixel). When the plane reaches the target the yellow pixel turns red to show the target has been eliminated.

General User Perceptions
In general, participants enjoyed the intuitive nature of the height and color controls. P18 stated that the pixels followed their finger "like a pet". P16 felt the height control allowed them to be "connected" with the display. The majority of participants wanted to see a system of a larger scale and higher resolution (e.g. 100×100 pixels). Participants also suggested faster response times for color and height changes.

DISCUSSION

Physical Animations
Participants successfully used ShapeCanvas to design a range of physical animations. Several participants designed content directly applicable to themselves (Physical Typography – all participants visualized their name) or their personal interests (P4, walking trail; P9, dynamic board game), and occupation-related visualizations (P15).

Interaction Patterns
Bimanual interaction emerged as the dominant interaction pattern. We observed participants quickly learning to efficiently use both of their hands for direct interaction. Future design environments should try to take advantage of the direct physical interaction possible with such displays (rather than trapping users in desktop environments). P3 described the interaction as "playing the piano where you use both hands for better control of particular keys". The tap and hover interaction for increasing the height of a pixel was well received by users. Future iterations of ShapeCanvas will aim to increase the parallel use of both hands.

Limitations and Generalizability
We used a small (4×4 pixel grid) display with simple interactions for novice user content design. This demonstrated that users were able to use low-level configuration to build physical animations. However, such interaction methods would need adapting to scale for large physical pixel displays. We also observed a diverse range of application areas. The choice of applications was likely influenced by the capabilities of the display, but in all cases, would only improve in quality on high-resolution displays. Larger scale content creation can be enhanced by enabling adjustable actuation speed, and concurrent multi-pixel interaction and color selection.

Future Developments
The observations from this study better position ourselves to develop such a larger scale system. The addition of a color palette on the screen interface would serve to reduce color selection time, as would a physical "brush" similar to Ryokai et al.'s I/O Brush [16].

CONCLUSION
The key objective of this work was to allow users to directly interact with a shape-changing display to generate their own content. We demonstrated how novice users can create physical animations using low level interactions for controlling the height and color of individual pixels. The key findings from this exploration are: (1) Simple, small shape-displays are useful for informing interaction design and discovering novel application areas, (2) Novice users successfully designed a diverse range of physical animations, suitable for informing future design environments, and (3) users quickly learned to take advantage of the spatial affordances of the shape-display. These findings provide a starting point for the construction and evaluation of content design environments for shape-changing displays.

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