Morphace: An Integrated Approach for Designing Customizable and Transformative Facial Prosthetic Makeup

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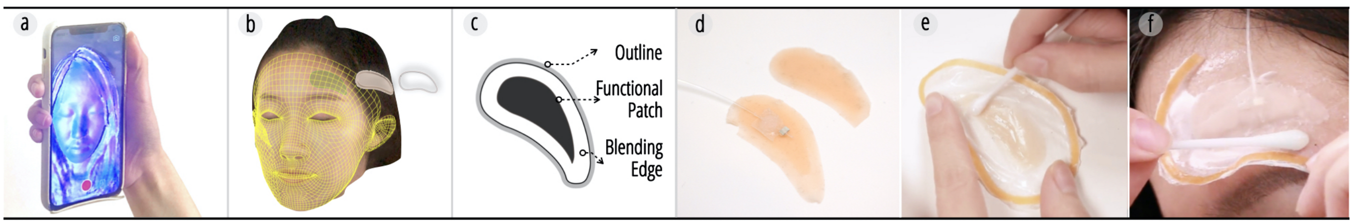

Figure 1: Morphace is a computer-aided fabrication approach that blends transformative wearables with the native skin using prosthetic makeup techniques. Morphace's fabrication process consists of: (a-b) designing and simulating on a scanned face, (c-d) fabricating functional primitives, and (e-f) applying the prosthetic patch.

ABSTRACT

On-skin electronics are an emerging group of interactive devices, with challenges in both engineering functionalities and design aesthetics. One design approach that lacks extensive exploration is combining prosthetic makeup with transformative wearables that generate dynamic output modalities. We propose a design approach called Morphace that imbues prosthetic makeup with customizability and transformative properties, which allows wearables to 'camouflage' on the original face and transform it. We use a case study on the face for its rich affordance of expressions and high visibility, which emphasizes the appearance of epidermal electronics. We developed a three-step computational design and fabrication workflow that integrates the prosthetic makeup process to fabricate functional primitives. We further explore the utility of Morphace through interactive experiences in social communication, facial augmentation, and self-expression. We believe Morphace offers an integrative approach that enriches current wearable solutions and enables creative output modalities and affordances for designing future on-skin shape-changing interfaces.

*Both authors contributed equally to this research.

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CCS CONCEPTS

• **Hardware** → **Emerging interfaces**.

KEYWORDS

Wearable, Shape-changing interface, Prosthetics

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1 INTRODUCTION

Wearable electronics offer unique interaction through their proximity to the body and access to biometrics, and they are becoming increasingly common. Typical approaches include integrating electronic functions into conventional artifacts (e.g., clothes, eyeglasses, and watches), or novel engineering or material science solutions to make the on-skin electronics as thin and transparent as possible [24, 50, 52]. Most engineering efforts focused on the flexibility and complexity of the wearable, leaving the electronic parts visually exposed. Meanwhile, a type of wearable device called "Beauty Technology" [48] hides electronics into cosmetics [25] and accessories [23] to enhance the physical appearance and increase the possibility of integrating into wearers' daily life. One beauty technology prototype uses special effects (FX) makeup to hide the sensors that detect facial muscle movements [46]. While this prior work of leveraging prosthetic makeup to hide electronic components showed great promise, it only focused on embedded sensing and did not explore the rich design space of output modalities that can be afforded by engineered soft materials that are compatible with the prosthetic makeup process. Our research looks into how to integrate transformative material and electronics such that they become part of our body and can be used for more expressive output modalities. We propose a method that combines prosthetic makeup, which already helps on-body appendages integrate with actors' native skin, with shape-changing and property-tunable wearables, thereby increasing the expressive and interactive potential of shape-changing interfaces on the face.

The film industry is already capable of producing realistic prosthetic makeup. We noticed how prosthetic makeup (i.e., special-effects makeup) artists make artificial, on-body appendages highly believable. A combination of art and science, prosthetic makeup is the process of using sculpting, molding, and casting techniques to create advanced cosmetic effects, and it plays a crucial role in stage performance and medical recovery. We describe the technical details of prosthetic makeup in the Background section. In this paper, we introduce Morphace, a novel approach to solving design challenges of aesthetics and functionality. We propose the integration of conventional prosthetic makeup techniques with the computational design and fabrication of compliant, transformative wearables out of silicone elastomers, a novel combination that lacks exploration in its potential design space and applications. To achieve our aesthetic goals, we developed a three-step design and fabrication process (Figure 1). First, we select a target region from a 3D scan of the wearer, computationally flatten the chosen region, and generate digital files for the functional primitive fabrication and prosthetic makeup processes. Next, primitives with different functions are fabricated layer by layer. We also describe fabrication techniques for creating functional primitives that enable the dynamic changes of prosthetic makeup. Finally, the functional patch is applied to the wearer's face using our tailored prosthetic makeup techniques. We chose the face as the specific body part to exemplify our approach, as the face is one of the most challenging parts to be augmented, from the perspective of prosthetic makeup. From a design perspective, the face is one of the richest parts, in terms of its dynamic changes in shape (e.g. dimples and wrinkles), color (e.g. blush and paleness), pattern (e.g. freckles and birthmarks), and medium (e.g. tear and sweat). In a later section, we describe the unique design space Morphace enables. We demonstrate the application of Morphace through a series of functional primitives. Many interactive or functional scenarios can be mapped onto the face, including augmented or altered facial expressions and emotional states. Beyond the general population, these solutions may be adapted for clinical populations, like paralysis patients who hope to enrich their facial expressions or stroke patients seeking facial rehabilitation. This approach can even be extended to novel use cases, including the use of encoded freckles for facial identification. In short, the contributions of the paper are:

- A novel and integrated approach to combine prosthetic makeup with transformative wearables, to have the external patches 'camouflage' on the original skin, and generate dynamic and interactive output modalities.
- A customized three-step workflow that involves computational design, primitive fabrication, and tailored prosthetic makeup.
- A design map and a corresponding collection of transformative skin patches to augment different aspects of a morphing face, including dynamic changes in shape, color, and medium.
- Example applications for augmenting facial expressions, emotional states, muscle training, and information displays.

2 BACKGROUND

Prosthetic makeup (i.e. special effects or FX makeup) is considered the art and craft to transform personal facial identification [42]. It is the process of using prosthetic sculpting, molding, and casting techniques to create advanced cosmetic effects [7]. Prosthetic makeup is widely used in film and theater performances and was revolutionized by John Chambers in such films as Planet of the Apes and Dick Smith in Little Big Man [7]. It is an artistic technique to augment facial morphology or texture. Silicone is the most commonly used material for prosthetics. The texture and flexibility of silicone make prosthetics look significantly like real skin. Artists then use pigments to color the silicone to create the translucent look of human skin [7].

The key to applying realistic prosthetic makeup is blending. In order to achieve seamless integration, the edge of the prosthetics should be as thin as possible. Thus, artists need to create high-precision molds and strictly control the appliance's thickness. The prosthetics can be glued to the skin using various types of adhesives, such as liquid latex or medical-grade adhesives [7]. Cap plastic, a soft plastic melted in acetone, is often used to cover the silicone appliance for blending. After the prosthetic is applied to the skin, the edge of the cap plastic film is dissolved using acetone and blended smoothly with the skin. To make the prosthetics look more realistic, artists often use silicone-based paints, alcohol-activated pigments, or cream foundation to create a more skin-like appearance [7]. Since the practice is mostly artistic-driven, the use cases are very diverse. Even though many commonly accepted methods exist, different makeup artists may have their unique craft techniques, and there are no settled rules or quantitative evaluations. We had to tailor the general knowledge to our specific needs.

One challenge in our work is to effectively integrate the process of conventional prosthetic makeup into a computational design pipeline, which allows users to simulate the on-skin visual effects and generate digital fabrication files to embed functional components. Prior work in the HCI community has paved the way for embedding electronics in FX (special effects) makeup for sensing muscle movement [46]. Although not for on-face application, using silicone and pigments to create biomimetic artificial skin with sensing capabilities has been explored in a greater depth as well [44]. In our paper, we build on top of these prior work mainly focusing on sensing, and try to expand the transformative output modalities (e.g., shape changes and phase transitions). In the following section, we will discuss prior work in this area in greater detail and how our work contributes to this area.

3 RELATED WORK

3.1 On-skin Interfaces and Beauty Technology

Including the human body in the loop of human-computer interaction creates connectedness between the body and information [17]. Specifically, researchers look to the skin as the new platform for hosting or being the next generation of interfaces for sensing and interaction [38, 43, 58]. Making electronics wearable also allows direct haptic feedback to the skin. Researchers have developed worn devices that communicate geometric shapes through dragging of the skin [4, 15, 19]. Kao et al. focused on the tunability of the texture of the interfaces [22]. Crucial to the immersive virtual reality experiences, Wilberz et al. developed a worn exoskeleton that provides facial haptic cues such as wind and warmth [53]. Efforts in recreating and enhancing the capabilities of the skin are also crucial for rehabilitation, namely patients with facial paralysis. Partial and full robotic masks are developed for post-surgery therapy [12, 20, 21]. Although not for wearable applications, Skin-On [44] created by Teyssier et al. is artificial skin for devices with skin-like textures that enable new input gestures, and Yu et al. encapsulates NFC circuits within silicone to allow wireless haptic feedback for virtual reality applications [57].

As technologies for wearables become more robust and the integration of electronics with the body becomes more ubiquitous, the call for customizable, aesthetic, and expressive design will be more eminent [35]. Katia and Fuks introduced the term "Beauty Technology" to describe electronic components that can be hidden in everyday beauty products [48], such as eyelashes and eyeshadow [25], hair [9, 47], and fingernails [23]. With the vision of beauty technologies, cosmetics that fuse skin with aesthetic and interactive technology have been long sorted out. These cosmetic makeups were designed to be indistinguishable from the human body [26, 48]. Most related to our work is special effect makeup used to sense muscle movement and use facial expression to control the environment interactively (e.g. turning on a light) [46]. In addition to cosmetic and prosthetic makeup approaches, tattoo is a popular and natural metaphor for second-skin interfaces [27, 51, 52], enabling integrations of haptic feedback [54], sensing, and display [6, 24]. More invasive approaches, such as the Dermal Abyss, directly integrate conductive ink into the tattoo process [49].

While leveraging prosthetic makeups to embed sensing has been introduced in beauty technologies [46], we believe the prosthetic makeup approach is still underexplored, especially for transformative output modalities. In our work, we explore how prosthetic makeup can be used to create expressive output. Unlike normal makeup techniques, prosthetic makeup provides more flexibility to integrate functional components that are thick or volumetric. Morphace takes advantage of prosthetic makeup to push the limit of integrating transformative wearables onto the face with dynamic expressions.

3.2 Actuation and Sensing Techniques with Soft Materials

Breakthroughs in soft robotics, a class of elastic, deformable devices, has allowed sensors and actuators to be embedded in soft bodies, giving them properties closer to biological organs and tissues [29]. Prior work in HCI has developed creative on shape-changing interfaces using actuation techniques, such as pneumatics [39, 55], fluidics [28, 33, 39], tendon-driven systems [1, 41], and the use of thermoresponsive material [16, 32]. Most of these techniques are used to create shape-changing objects or wearables but not for on-skin applications or more specifically, with prosthetic makeup techniques. We propose a design and fabrication pipeline to integrate these techniques to create transformative prosthetic makeup with dynamic output modalities. Besides actuation, a large body of research on flexible on-skin sensors that detects touch input and biosignals [30, 37]. Different from previous designs, Skin-On embeds gesture touch input sensing in a biomimetic artificial skin with skin-like texture and deformation [44]. While our work does not include sensing, we believe sensors can be integrated into our design as prior work has shown.

3.3 Augmented Facial Expression

Facial expression provides rich non-verbal communication and has been explored by many to enrich current interaction paradigms. Though controversial, psychologists believe the reading of facial expressions can convey one's emotions [11]. Based on this theory, researchers have developed tools to translate non-verbal cues from facial expressions to haptic displays [31]. Chen et al. assessed how showing facial expressions in AR can promote social skills of adolescents with autism [5]. The expressiveness of one's facial movement enables naturally embodied interaction. Research has found that users convey personality through their choice of face filters on social media platforms like Snapchat and Instagram [40]. Intelligent makeup platforms have also emerged as a way to satisfy the need for bringing creativity to self-expression [36, 45]. Tools such as Adobe Fuse also help users generate facial features by adjusting fine parameters of the face (e.g., the distance between the eye and skin texture). Beyond the main part of the face, Huang et al. extended expression through the parts of the ear [18].

4 MORPHACE

To create prosthetic makeup with transformative output modalities, we used a bio-inspired design process, where the Morphace skin mimics existing output or transformation modalities of human skin (e.g., forming wrinkles or generating freckles), and engineered these output modalities to be tunable and responsive for interface design purposes.

4.1 From Human Skin to Morphace Skin

We drew analogies from the biological structure of the human skin, which consists of layers with unique properties and functions [10]. We also sought inspiration from prior work Skin-On [44] which created artificial skin with a tri-layer structure: visual, sensing, and kinesthetic layer. Different from Skin-On, which mainly focuses on sensing and aims to give devices artificial skins, we focus on dynamic output modalities, and by leveraging prosthetic makeup techniques, we make our systems more closely integrate with and augment the human skin (especially the face in this work). Here we draw an analogy between the human skin layers and the relating Morphace skin layers (Figure 2).

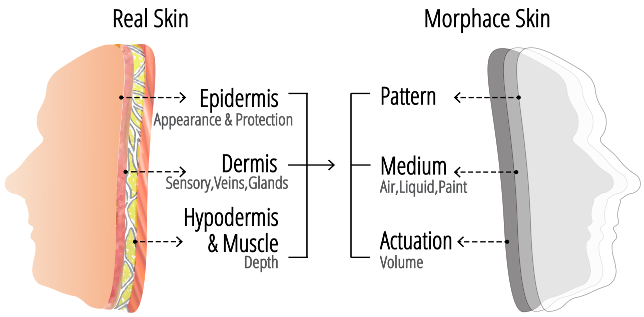

Figure 2: Morphace skin mimics the structure and function of human skin with enhanced transformative abilities.

4.1.1 Epidermis :: Pattern. Epidermis is the outermost layer that shows the skin tone and texture while protecting the deeper layers of skin underneath it. Morphace's pattern layer acts similarly and outputs dynamic surface appearances (e.g., color and pattern) while protecting and hiding the functional primitives underneath.

4.1.2 Dermis :: Medium. Dermis is the second layer of human skin that hosts sensory receptors as well as veins and sweat glands. Morphace's medium layer mirrors the dermis and hosts medium such as liquid, air, and pigment.

4.1.3 Hypodermis & Muscle :: Actuation. Hypodermis is the layer between the skin and muscle and provides depth. Since we want to blend the Morphace skin with the natural skin, Morphace skins need to be relatively thin. We combine the hypodermis and muscle layers to host pneumatic or tendon-driven actuators that give Morphace the volumetric transformative abilities.

4.2 Transformative Prosthetic Makeup

Morphace intends to broaden the integration, expression, and interaction capabilities of on-skin electronics by creating dynamic output modalities. We achieved this goal by developing dynamic shape-changing primitives and applying realistic prosthetic makeup techniques. Figure 3 shows how making static prosthetic makeups dynamic introduces new design spaces and interaction paradigms.

4.2.1 Properties. Enabled by the tri-layer structure, Morphace can have a wide variety of physical properties, including thermochromic paint for color and pattern (Figure 3a-b), water for medium (Figure 3c), tendon-driven and pneumatic actuators for shapes (Figure 3d-f). While dynamic output properties such as color and shape changes have been explored in the context of interactive beauty technology [48] or wearable [55], they have not been systematically studied in combination with prosthetic makeup processes previously.

4.2.2 States. States represent the changes and transformable aspects of each property achieved by Morphace primitives. Here, we outline the different parameters of state changes (Figure 3). In terms of geometry, Morphace can have surface (e.g. lifting eyebrows), linear (e.g., wrinkles), and volumetric changes (e.g., dimples and cheekbones). Additionally, Morphace can have color change (e.g., blush), texture change (e.g, freckles and birthmark), or medium change (e.g. tears and sweat).

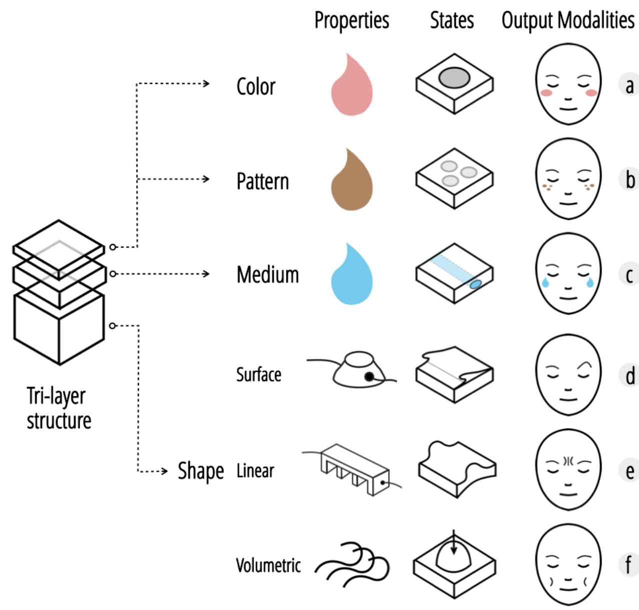

Figure 3: Each property of Morphace has its transformative state that conveys the corresponding output modalities.

4.2.3 Output Modalities. The dynamic change of Morphace enables interactive applications, unique aesthetics, and affective expressions (Figure 3). The unique placement of Morphace on the face connects the functions of interactive applications to the function of facial organs (e.g. Morphace actuates the frontalis muscle is to lift eyebrows and augment facial expression). Morphace further leverages the innate richness of facial expression and on-skin placement to convey affect to both the wearer and bystanders.

5 USER DESIGN WORKFLOW

We developed a design and fabrication process for Morphace, by integrating computational design with a tailored prosthetic makeup process (Figure 1). A 3D mesh surface from a scanned human face serves as the input for our computational tool. Designers can then select an area on the mesh surface where the Morphace patch would be placed. The tool flattens the chosen region and generates all the digital files necessary for both the patch-making and prosthetic makeup application processes. Designers then create functional primitive layers using the design files generated from the simulation. Finally, designers combine the layers and use modified prosthetic makeup techniques to apply Morphace onto the human face and blend it in.

5.1 Step 1: Design and Simulate on Scanned Face

Facial features are unique to each person and important to one's identity, e.g. the size of one's cheeks varies from person to person, so customizability is an important design criterion that we considered. In addition, even though our primitives are made with stretchable materials (e.g., silicone), we need to make sure the primitives can fit cozily along the contour of the face to ensure a smooth blending.

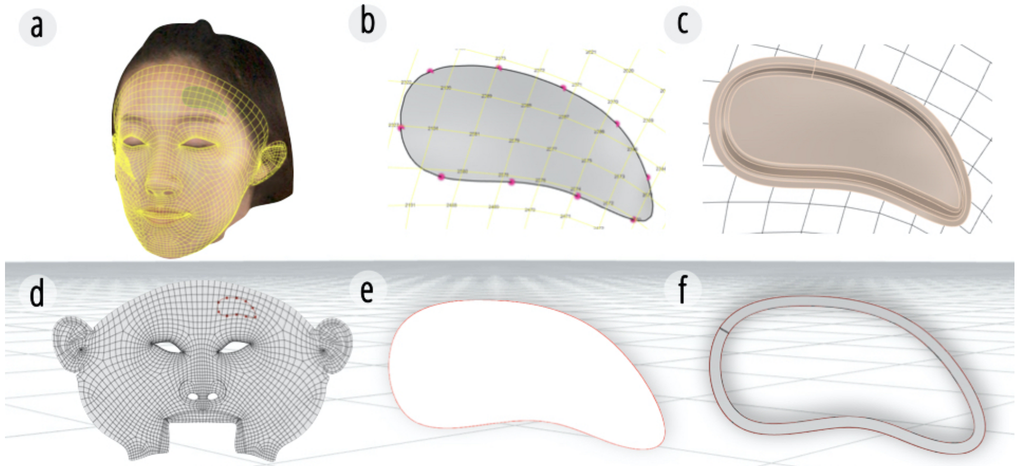

Figure 4: A 3D mesh of a user's face is used to select a specific area for prosthetic application and generate outlines and the casting mold for fabricating the transformative patches.

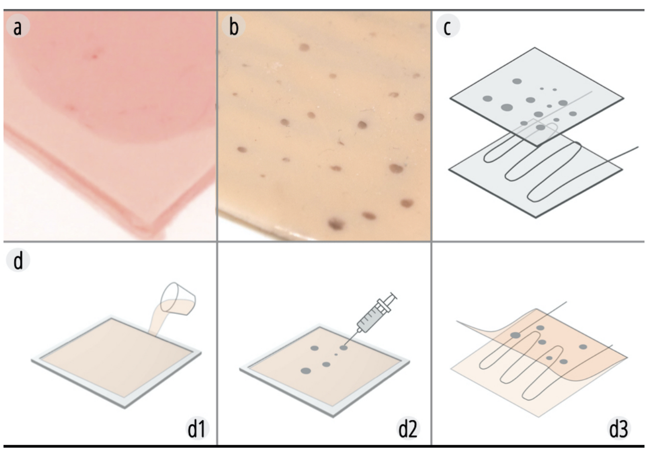

Figure 5: Sample (a-b), exploded view (c), and fabrication process (d) of transformative freckles and blush.

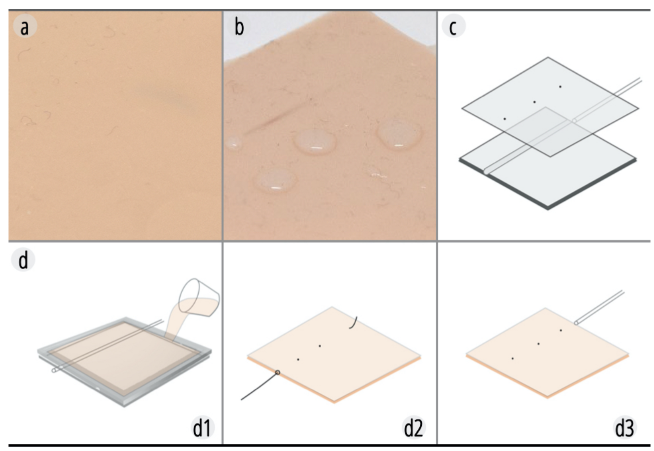

Figure 6: Sample (a-b), exploded view (c), and fabrication process (d) of transformative tears and sweat.

To customize the outline and size of each primitive to a target user, we developed a computational design pipeline in Rhinoceros with Grasshopper. The 3D mesh of a user's face is gained through a 3D scanning tool (Bellus3D[1]) and imported into Rhinoceros. We then change the model topology from triangle mesh (T) to quad mesh (Q) (Figure 4a). The 3D mesh (Q) is then flattened into a 2D mesh (F) using Zbrush's UV master plugin[2] (Figure 4d). The user can draw a curve (C) on the 3D mesh (Q) to enclose the region where they wish to create a prosthetic patch (Figure 4b). A preview of the patch is then generated (Figure 4c). At the same time, the vertices on the sketched curve (C) are mapped onto the 2D mesh (F) using barycentric coordinates mapping [14] (Figure 4d). The curve (O) connecting vertices on the 2D mesh (F) is then used to extrude the mold to be 3D printed for the primitive fabrication (Figure 4c). An offsetted outline of the curve (O) is also generated to create the frame for the prosthetic makeup step (Figure 4f).

[1]https://www.bellus3d.com/
[2]https://pixologic.com/zbrush/features/UV-Master/

5.2 Step 2: Fabricate Transformative Functional Primitives

Using the outline generated from the simulation, we create a negative mold of the primitive. We 3D-print the mold using an FDM printer. Each functional patch has three layers. The top layer and bottom layer are made of silicone elastomer (Ecoflex 0030, Smooth-On[3]). The middle layer, which is the functional layer, can be made of different materials and structures corresponding to various transformations. We then sandwich the middle layer and bond the top and bottom layer with a thin layer of uncured silicone. Here we show how we fabricate four primitives that involve actuation or change in texture.

[3]https://www.smooth-on.com/products/ecoflex-00-30/

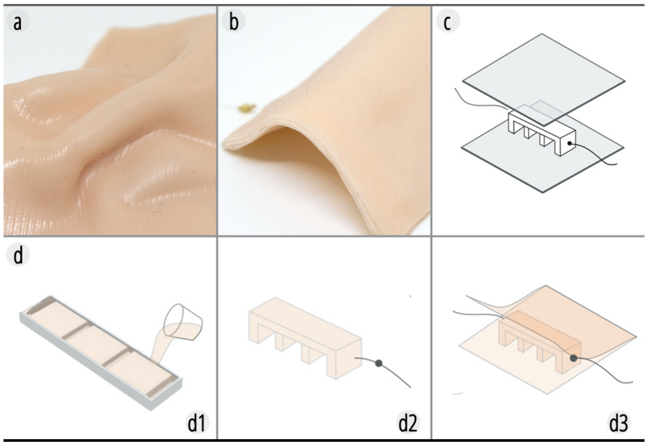

Figure 7: Sample (a-b), exploded view (c), and fabrication process (d) of transformative wrinkles and cheekbone.

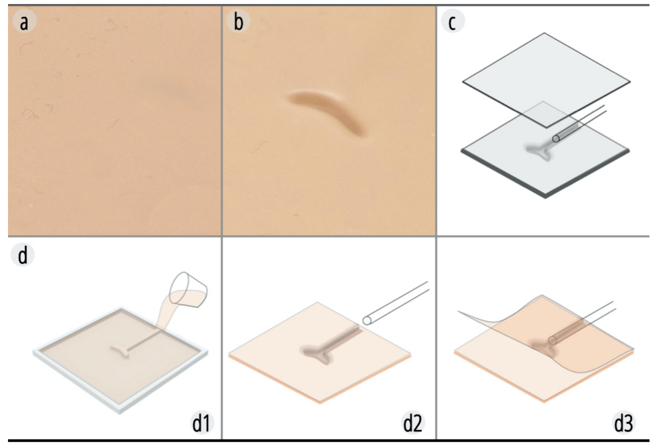

Figure 8: Sample (a-b), exploded view (c), and fabrication process (d) of a transformative dimple.

5.2.1 Freckles & Blush. We mix EcoFlex with thermochromic pigment and manually inject the mixture into a layer of uncured silicone where we want the color to change. We then embed conductive threads[4] between the thermochromic layer (top layer) and the bottom layer. When the conductive thread is connected to a power supply, it heats up the thermochromic pigment at around 31°C, the pigment disappears and blends in with the rest of the Morphace skin. Note the bottom silicone layer acts as a protective layer for the human skin from the heat generated by the conductive thread. We will discuss this further in our discussion section (Figure 5).

5.2.2 Tears & Sweat. We embed a thin plastic tube in uncured silicone to create a fluidic channel. After the silicone has cured, we gradually pull out the plastic tube but leave a small part in and then use silicone glue to seal. We then poke small holes through the top layer of silicone to create pores for secretion. We use a syringe to manually pump water through the tube to create the sweat/tear effect (Figure 6).

5.2.3 Wrinkles & Cheekbone. After designing and molding, we first create a tendon with anchors with relatively stiff silicone elastomers (Dragon Skin, Smooth-On[5]), and then we thread through the anchors with a fishing line. The distance between the anchors determines the folding effect of bones or wrinkles. For wrinkles, we clamp two jewelry crimps at the two ends. As for cheekbones, we place a jewelry crimp at every anchor. We then use silicone glue to fix the tendon onto the top and bottom layer silicone. When the fishing line is pulled, the surface folds, which creates the wrinkle/cheekbone effect (Figure 7).

5.2.4 Dimple. We cast silicone in a negative mold to create a chamber for the dimple. Then, we place a plastic tube at the edge and cover the chamber with a thin layer of silicone. We seal the edges with uncured silicone and manually deflate the chamber using a syringe to create the dimple effect. The chamber is small enough that a pump is not needed to deflate it (Figure8).

[4]https://www.adafruit.com/product/640
[5]https://www.smooth-on.com/product-line/dragon-skin/

5.3 Step 3: Apply Prosthetic Makeup

As described in the Background section, conventional prosthetic makeup is an artistic and manual practice that requires practice for perfection. However, by leveraging our digital design process, we improved the controllability and accuracy of this process and made it more accessible to novice users who do not have experience with prosthetic makeup.

After the functional patches are made, we can then blend them onto the chosen areas of the face. There are two major parts in applying our facial prosthetics: prosthetics building and on-skin blending. The prosthetic patch contains four layers from bottom to top: an outline, bottom layer cap plastic film (Q Ballz, Smooth-On[6]), silicone functional primitives, and top layer cap plastic film (Figure 9a). The cap plastic layers are used to fix the silicone primitives stably and seamlessly to human skin. The outline, generated by the computational tool, acts as a frame that tightens the cap plastic film layers to keep them from sticking together.

We studied traditional prosthetics making methods and developed our own prosthetic structure and blending procedure after many iterations. Existing common methods spray cap plastics before and after uncured liquid silicone is poured. Tailored to our transformative Morphace primitives, we developed a more modular and flexible approach by separating silicone fabrication from the rest of the prosthetics building process.

5.3.1 Prosthetics Building. We first place the outline on the silicone base pad (Figure 9a), which allows the cap plastics covered prosthetics to be easily removed in the later process. We then pour a small amount of liquid cap plastic within the outline and use a wooden stick to spread the liquid evenly around the area enclosed by the outline (Figure 9b-c). After the cap plastic is fully cured and looks like a thin piece of film, we place the prepared functional patch on top of the film in the center of the frame (Figure 9d). We then pour another layer of liquid cap plastic onto the functional patch and allow it to cure (Figure 9e). When spreading the cap plastic, we keep the film as thin as possible and avoid leaving small

[6]https://www.smooth-on.com/products/qballz/

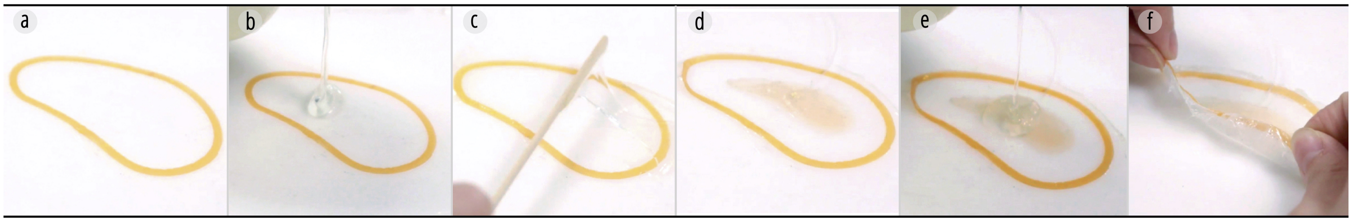

Figure 9: In order to build the prosthetic patch: (a) Place the premade outline on a silicone base pad; (b) Pour a layer of cap plastic liquid; (c) Evenly spread the cap plastic liquid with a stick; (d) After the cap plastic is cured, place the premade functional patch at the center of the outline; (e) Spread another layer of liquid cap plastic on top and allow it to cure; (f) Remove the finished prosthetics from the silicone base pad.

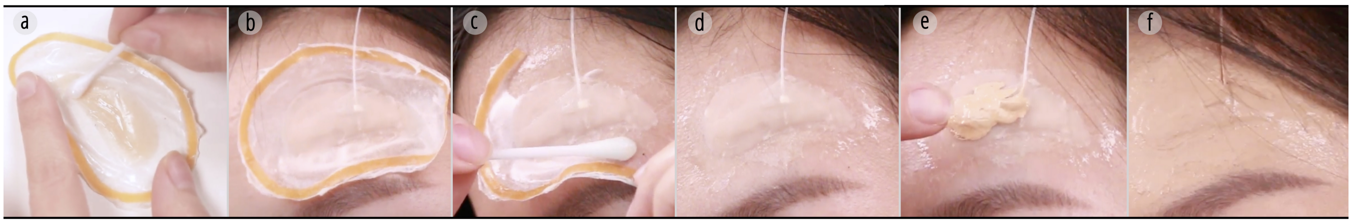

Figure 10: To blend the prosthetic patch onto the skin: (a) Apply skin adhesive on the prosthetic primitive; (b) Place the prosthetic on the skin; (c) Soak a cotton swab with acetone to dissolve the edge of the cap plastic film and remove the outline; (d) Prosthetic primitive blends seamlessly onto the skin; (e) Apply liquid foundation on top of the prosthetic; (f) Finished look.

gaps. This step is very crucial because the thickness and porousness of cap plastic layers directly influence the blending performance. When the top layer cap plastic is fully cured, we brush the surface with some powder and carefully separate the finished prosthetic patch from the silicone base pad (Figure 9f).

5.3.2 On-skin Blending. We first apply a thin layer of adhesives (Skin Tite, Smooth-On[7]) on the prosthetic patch (Figure 10a). Next, we place the prosthetics on top of the desired area on the face and hold the prosthetics in place for a minute by hand until it sticks (Figure 10b). Then, we soak a cotton swab with acetone solution and attentively dissolve the edge of the cap plastic film along the outline, and we gradually remove the outline during this process (Figure 10c). After the outline is removed, the edge of the cap plastics films should be blended seamlessly onto the skin (Figure 10d). Then, we apply liquid creme foundation around and over the prosthetic patch to balance the skin tone (Figure 10e), and we dust it off with some power to reduce reflection and create a more realistic look (Figure 10f).

6 EXAMPLE APPLICATION

The ultimate objective of Morphace is to provide a new computational design and fabrication process that can blend in with the skin and support dynamic output modalities. We hope to illustrate how Morphace's dynamic, multifunctional patches can enable new interactions and applications. To demonstrate and evaluate the feasibility of this approach, we provide three different applications on different locations of the face with varying associations of emotional expression, interactive display, and facial morphological changes.

[7] https://www.smooth-on.com/product-line/skin-tite

6.1 Emotion Augmentation

A direct application of Morphace's functional patches is facial augmentation to create emotional expressions on demand. Here, we create a sweat and blush combination (Figure 11). Showing vulnerability can build deeper connections and rapport [3]. However, sometimes it can be difficult to express such feelings due to habitual self-defense or at a loss of words. In this scenario, we envision users can trigger the artificial sweat and blush, akin to typing an emoji reaction in a digital conversation, to vividly represent their feelings. We also imagine that other micro-expressions can be shown through Morphace patches to "rescue" or alleviate social awkwardness. For example, users can appear more excited in front of loved ones to show support even when they are physically exhausted.

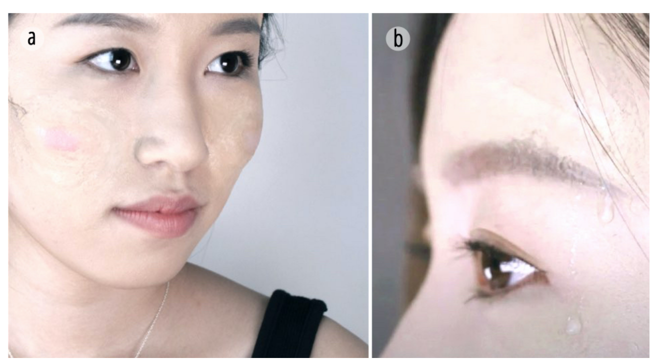

Figure 11: Morphace augments emotional responses, such as (a) blushing and (b) sweating.

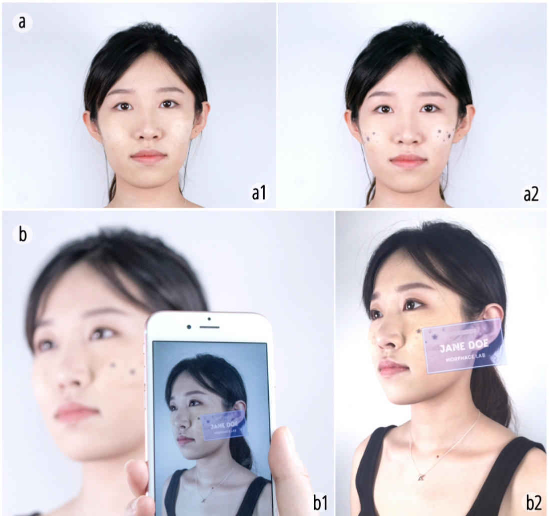

Figure 12: Morphace enables dynamic information display through features such as e-freckles, and allows (a) on-demand visibility and (b) the view of encoded information.

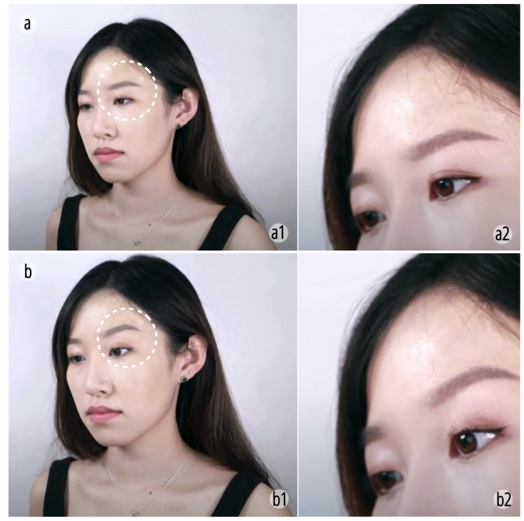

Figure 13: Morphace's face-sculpting patch (a) blends seamlessly with the skin and (b) creates visible changes to the face, such as lifting the eyebrow.

6.2 Dynamic Information Display

Our face is the arguably most important social identifier. With facial recognition technology becoming more popular, the face serves an ever more important role in our technology-integrated life (e.g., face as a cyber identifier). Inspired by face filters in social media apps, we envision that freckles can be used as a form of dynamic information display. Here we show an application built using an Augmented Reality (AR) toolkit (Vuforia[8]) that can read the artificial freckles and overlay information about the person in AR (Figure 12b). Different from makeup artists that draw freckles on the face, the Morphace freckles can be turned on or off (Figure 12a). Additional use cases of such unique facial tags may include programmable identity recognition as an alternative to facial recognition.

6.3 Face Sculpting and Rehabilitation

We can envision changing facial morphology dynamically for either performance or training purposes. As an example, we created a pull-string patch that can lift the corner of the eyebrow (Figure 13). Users can also sculpt other facial features such as wrinkles and dimples (Figure 7-8). As we mentioned in the related work section, there is a rich body of literature that addresses muscle training on the face with wearable techniques. We believe our contribution is that the training system can be hidden and worn without affecting social customs.

7 DISCUSSION, LIMITATIONS, AND FUTURE WORK

7.1 Fabrication

We showed how we adapted and simplified traditional prosthetic makeup techniques to create modular, transformative prosthetic wearables. Each prosthetic patch is customized and individually fabricated. From design to application, this process required on average 2 hours, where the prosthetic makeup process took around 15 minutes. In the future, we envision users can have a toolkit of different transformative wearable patches. They can then integrate the patch during their routine makeup process with ease.

7.2 Portable Actuation and Control Unit

We demonstrated in our transformative functional primitive section the use of actuators (e.g., pneumatics, fluidics, tendon) and display devices (e.g., thermochromic paint, fluidics). While our work mainly focuses on the design space and fabrication process of the prosthetic patches, we did not conduct in-depth explorations of the form factor and portability of our electronic control systems (e.g., resistive heating circuits and hydraulic pump control units). However, we believe our prosthetic patches can be easily combined with more portable and miniaturized control systems as future work. In fact, prior work has already shown promising use of miniaturized air and liquid pumps for potential wearable use [2, 8, 55].

7.3 Functionality

While the focus of our design efforts is primarily on the integration of prosthetic makeup techniques with transformative outputs, our process does not preclude the integration of sensing and communication devices. The thickness of the prosthetic makeup and the blending process allow multiple layers of electronics to be embedded between the silicone layers. By leveraging existing sensing technologies [30, 44], we envision an integrated sensing and actuation system on the face to form a closed-loop interface that can blend in with the native skin.

7.4 Safety and Comfort

Skin secrets oil and sweat, and facial muscles constantly move, both making attaching wearable on top a challenge. In "Wearability

[8]https://www.ptc.com/en/products/vuforia

Factors for Skin Interfaces" [26], Liu et al. suggest on-skin interfaces should be thin, lightweight, and soft, and recommend using skin-friendly adhesives used in FX makeup, which we use for this work. Agreeing with [26]'s suggestion, we also suggest wearers should consult physicians before applying such devices onto sensitive skins. In addition, since Morphace directly attaches onto the skin, which may constrain natural muscle movements of certain parts of the face, future work should study the comfort of long-term wear as well as the wearability of the areas on the face, similar to the study done by Gemperle et al. [13].

7.5 Uncanny Valley

Our work pushes the boundary of the uncanny valley by augmenting the natural skin with visually indistinguishable artificial skin [34]. Social and cultural acceptance of prosthetic makeup in daily use depends on various aspects [42]. Compared to a full mask for the head, Morphace patches are less obtrusive, but we think further user studies are needed to evaluate the form factor of Morphace. We are also interested in understanding users' preferences for morphing features in different contexts. For example, how would users want a more 'native' texture (e.g., freckles) compared with a more 'creative' texture (e.g., a heart symbol) to show on their faces in different contexts?

7.6 Empirical Evaluations

The goal of Morphace is to offer the wearer a more expressive use of on-skin wearables. Ultimately, facial expressions and expressions through Morphace are highly subjective and can be interpreted differently across cultures. We hope to explore how the wearer and the observer perceive the effect created by Morphace, which merits future empirical evaluations.

8 CONCLUSION

In this paper, we introduced Morphace, an integration of soft and transformative skin patches with prosthetic makeup techniques and suggested use cases that involve dynamic output modalities. From a design perspective, we augment the native skin instead of creating a 'second skin' [56] since our skin patch 'camouflages' on the original skin. This enables novel design uses, including artificial tears, augmented facial expression and facial morphology, interactive blush and encoded freckles, etc. From an engineering perspective, we provided a new angle to develop on-skin, shape-changing interfaces. Instead of pushing the limit of the thickness and transparency of the material, we suggest using prosthetic makeup techniques to make transformative wearables on the skin.

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