GENERAL ARTICLE

Lovewear

Haptic Clothing that Allows Intimate Exploration for Movement-Impaired People

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ABSTRACT

People with disabilities often face physical, political, and societal barriers in expressing their sexuality. The lack of inclusivity in the sex toy market does not support an autonomous experience for impaired individuals who cannot operate toys without external assistance. Lovewear is a collaborative art-science project that combines user-centered design principles with soft robotics integrated into textiles. The aim is to offer an autonomous experience through haptic feedback, allowing self-exploration of intimate sensations and sexual pleasure to females with motor impairments. A pillow interface activates an underwear garment: While caressing and touching the pillow, the wearer triggers the underwear's inflatable i actuators. This transdisciplinary project used a mixed-methods research design; the objective is to promote the embedment of technology into everyday garments, to improve the wearer's quality of life.

The Lovewear project has been partially funded by the European Union Horizon 2020 research and innovation program under ST ARTS and Re-FREAM, a research project that invites artists and designers to connect with scientists on common ground to rethink the manufacturing process of the fashion industry. Selected artists and technologists commit for nine months to a co-research and co-creation strategy using Re-FREAM's Art/Tech collaboration methodology; this methodology builds a cross-sectorial common space, an environment that enables a new mindset that strikes a balance between art, design, and technology. Within this new dimension of equality, the artist must reenvision their initial idea together with a technologist [1]. Under Re-FREAM's framework, the following partners came together for the development of Lovewear: Wear It, Berlin (hub manager), Fraunhofer IZM, Berlin (production of soft actuators), and EMPA Laboratory for Biomimetic Membranes and Textiles, St. Gallen (material testing). The project has also seen the support and collaboration of other professionals with a transdisciplinary approach: a psychologist and sex therapist, a biomedical engineer, and electrical engineers. This transdisciplinarity aims to develop true synergy between the different disciplinary perspectives [2].

Our contribution shows how technology development and direct application can work hand in hand, leading to more comprehensive outcomes. Design has an essential role in leading this transition, increasing the adoption and acceptance of robotics within different demographics. Soft robotics have been recently widely experimented with [3]; this project addresses them regarding the specific sex toys field within a more comprehensive, inclusive scope. Through our practice and with a focus on inclusivity, we are promoting technology embedment in everyday garments to augment their functionality, providing the wearer with a better quality of life.

The idea of bodies being spatially separated but electronically connected has long fascinated artists. "Our body is obsolete," as Australian performance artist Stelarc affirms. The artist's work is based on augmenting and amplifying the human body's capabilities; his posthumanist philosophy and speculative thoughts are expressed through prosthetics, biotechnology, and connected devices [4]. In his view, human beings are not well designed but flawed, with a certain degree of disability, which somehow equalizes us all.

"I would like to believe that technology offers us opportunities to break down and disrupt existing power structures. Sex, gender, and sexuality in particular could all be radically re-evaluated through the framework of technology," Sophia Lawler-Dormer states while interviewing Stelarc, who agrees and replies, "Technology standardises and equalises potential between the physical elements of sexes" [5].

Lovewear aims to empower humans and their bodies, connecting the self and the body, and facilitating a dialogue between people through their senses with the support of

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technology. Disabilities are not the project's core but a starting point that allows everyone to interact at the same level; the pleasure of people with disabilities is an objective but not the mere purpose of Lovewear.

Artist and researcher Elena Redaelli describes Lovewear:

> If these objects were thought [of] as single pieces, or like a procedural performance, not meant for a large industrial production, they could have been framed in the contemporary art context. They would be considered functional sculptures or relational, cross-disciplinary artworks that could freely move into a hybrid space without needing to be labelled while mixing textile materials, science, technology, and social activism. The boundary between art and design is fluid: definitions shift their meaning taking many forms. Just like the thread in the intertwining of weft and warp speaks to us of material culture and can now convey digital information, encoded through algorithms, about our most basic physiological functions [6].

Lovewear could be considered a form of activism. This practice combines the creative power of the arts to move us with the strategic planning of activism necessary for social change [7]; the project uplifts the intimacy and sexuality of people with disabilities, which can develop social inquiries, highlighting challenges people are facing and empowering the community.

DEFINING THE PROBLEM: THE STIGMA OF DISABILITY AND SEXUALITY

Over a billion people worldwide are affected by disability, which means about 15% of the world's population [8]. At least a fifth of these, about 110–190 million individuals, are forced to cope with very considerable difficulties in ordinary life; it is estimated that 75 million people need a wheelchair on a daily basis, which represents 1% of the world's population [9]. Furthermore, the rates of disability are growing due to the aging of populations. A disability may be present from birth or occur during a person's lifetime due to biological or non-biological reasons. A partial or total loss of function of a body part is generally called "motor impairment"; this can be caused by a traumatic injury, a congenital condition, or disease onset correlated with age. The target group for experimental evaluation comprised motor-impaired users having spinal muscular atrophy, spinal cord injury, or muscular dystrophy. Spinal muscular atrophy is a rare genetic disorder that leads to progressive muscle weakness and loss of muscle mass (atrophy) in the muscles closest to the trunk of the body, such as the shoulders, hips, and back [10]; it occurs in about eight out of every 100,000 live births and affects approximately one in 6,000 to one in 11,000 people worldwide. Movements like walking, crawling, head and neck control, swallowing, and breathing are compromised or impossible. Spinal cord injury disrupts the normal functioning of the spinal cord, and the communication between the body and the brain is compromised or completely severed; trauma is typically attributable to motor vehicle crashes, falls, violence, work-related injuries, sports-related injuries, or suicide attempts. Muscular dystrophy is a genetic disorder that results in progressive muscle loss and weakness, which initially manifests as difficulty in controlling movements and gradually progresses to a complete loss of different muscle functions.

Neuromuscular disorders and other motor impairments may affect one's social and sexual life. Disabling conditions frequently include decreased sensory input, a neurogenic bowel or bladder, impaired toilet use, and decreased genital sensation. An altered body image combined with overprotective parenting and lack of independence may hinder healthy social and sexual development in young adults [11]. Another important aspect of the sexuality of people with disabilities is the lack of representation: media has restricted the depiction of the human form to bodies that meet prevalent aesthetic standards, and as a result, sexuality as a source of pleasure and as an expression of love is not recognized for populations that have been traditionally marginalized in society [12]. Although sexuality is a human right, according to the United Nations and the Convention on the Rights of Persons with Disabilities, sex is still a taboo subject and the privilege of the few individuals with supportive friends and families. In most cases, sexuality is neglected, avoided, or punished. Moreover, the sex toy market does not consider differently abled bodies. As Article 25 of the UN Convention on the Rights of Persons with Disabilities states [13], it is the right of individuals with a disability to achieve the highest standard of health care without discrimination. Article 25 also recognizes access to appropriate and affordable assistive technology as a human right, which has resulted in increased awareness and advocacy worldwide [14]. Assistive technologies are tools designed to help people with disabilities to be as autonomous as possible, and recent years have been characterized by research and innovation in the fields of design and technology. In our perspective and practice, technology should be embedded in everyday life into objects that can improve aspects of a person's daily routine, that blend into products that anyone could use, and are accessible to users with special needs.

Persons with disabilities have the same sexual and reproductive health needs and desires as people without disabilities, although ignorance and attitudes of society and individuals can be a barrier [15].

Sex is one of the most stigmatized aspects of the life of a person with a disability, and Lovewear aims to give back sexual dignity and autonomy to those people.

SEX TOYS

Until the beginning of the twentieth century, genital massage to orgasm by a physician or midwife was a standard treatment for hysteria, considered at the time a common and chronic disease in women rather than a condition. Physicians legitimated the clinical production of orgasm in women as a treatment, since female masturbation was considered unchaste, and sexuality was seen as penetration by a male. More recently, researchers such as Alfred Kinsey and Shere

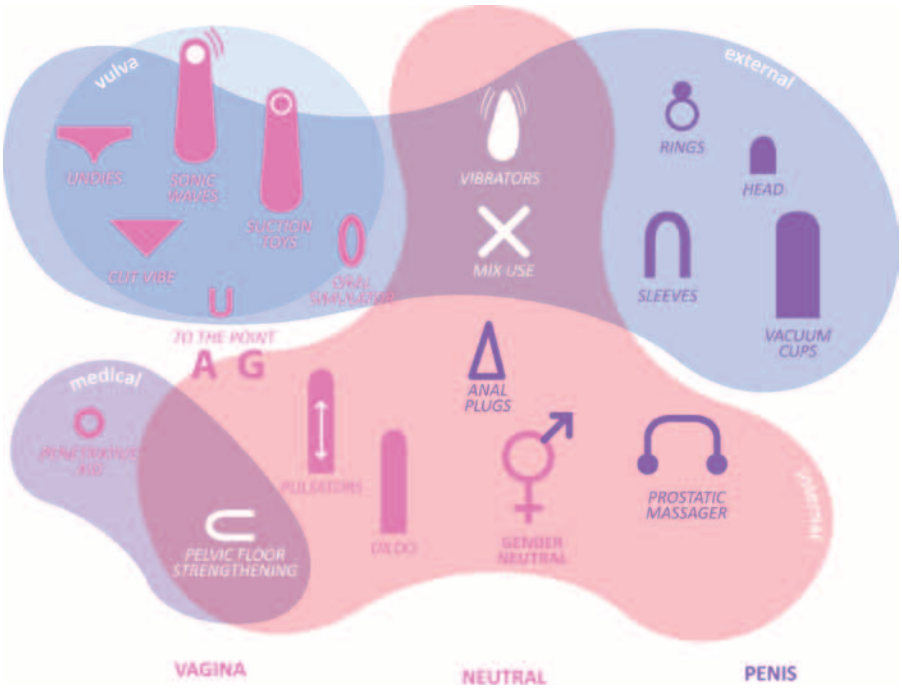

Fig. 1. Sex toys map. The map summarizes the sex toys available on the market by typology; the icons reflect the technology or the shape of the toy. On the left side are toys thought to be for the vagina; in the middle are gender-neutral types; and on the right side are those thought to be for the penis. Further categories address the use: internal or external. Some products are specifically aimed at improving health and well-being, such as those that strengthen the pelvic floor or ease penetration in cases of painful sex. (© Emanuela Corti and Ivan Parati)

Hite demonstrated that most women (more than 70%) do not regularly reach orgasm by means of penetration alone [16].

The vibrator, intended as a massage technology, disappeared at the beginning of the twentieth century to reemerge during the 1960s, marketed to consumers, and by the 1970s it was openly sold as a sex aid.

The most recent technological innovations have changed the way we interact, develop relationships, and embody sexuality. Teledildonics, haptic bodysuits, and gynoids [17] are now realities that have transformed human interactions [18]. Teledildonics, or cyberdildonics, are sex toys that allow people to have sexual encounters from remote locations [19].

In our research, to better understand the user experience, we mapped the sex toys currently on the market and listed what we perceive as relevant for their function and use. There is a variety of products, as shown in Fig. 1. We mapped products available for both genders.

Impaired mobility requires proper grip, comfort, and adaptability to diverse holding postures, strengths, and capabilities. It is relevant to the present study to note that few products can be used by a person with a disability.

For the study we used a methodological approach that combined an online survey with expert interviews and focus groups to evaluate people with disabilities' perceptions of sex toys in relation to sex, their view of pleasure and intimacy, and their awareness of their own body and their partner's body. The data helped us define guidelines for the development of the prototype.

The experts interviewed are Judith Glover, a lecturer in industrial design at the RMIT University in Melbourne, Australia, who specializes in social and sustainable design, with particular expertise in gender and sexuality; Rafe Eric Biggs, the founder of Sexability, an organization committed to improving sexuality and disability in the United States; and a sex counselor and founder of an important association for people with disabilities based in Spain, who prefers to remain anonymous.

The experts gave us important feedback for evaluating the available sex toys and helped us to set further requirements for the development of Lovewear.

USER ENGAGEMENT

The online survey was intended to provide understanding of how the lack of autonomy of movement-impaired people could affect their daily life, their body sensitivity, and their opinions and attitudes toward sex. The survey was initially proposed without any gender discrimination, although most of the respondents to the survey identify as female (67%).

Almost all the survey respondents agreed that sex is fundamental in the human experience and people with disabilities have the right to live it. Moreover, for most of them, sex corresponded to well-being, meaning both physical pleasure and positive emotions; affectivity and relationships with others were also stated as very important aspects of sex (Table 1, supplemental material).

The data confirms that sexual arousal and desire are normally present among people with disabilities, contrary to the dominant collective imagination that depicts people with disabilities as infantilized, vulnerable, and ultimately asexual [20]. Disability does not affect sexual arousal. Rather, it can affect the possibility of accessing sexual experience. Reduced mobility and limited genital sensitivity were the most frequently mentioned difficulties negatively influencing the access to sexual experience, both for intercourse with a partner (Table 2, supplemental material) and for practicing self-eroticism (Table 3, supplemental material).

For the participants, the genitals were the most frequently mentioned erogenous part of their body (Table 4, supplemental material). However, neck, chest, and breasts are also widely mentioned. This result seems to suggest that sexual sensations can be transferred to other parts of the body when the genitals' sensitivity is reduced. As concerns the body parts regarded as attractive in a sexual partner, the genitals, the breasts/chest, and the buttocks were the most frequently mentioned, in line with what is commonly associated with sexual attraction among people regardless of ability.

Most respondents (86%) described sex toys as erotic toys for adults, designed to stimulate a feeling of pleasure, while very few of them (only 14%) associated sex toys with deviant and perverse erotism. Moreover, 85% of the respondents agreed that sex toys could be used alone and with a partner. Despite the attitudes toward sex toys mostly being open and positive, less than half of the respondents (48%) had used them (Table 5, supplemental material) and 71% would like to use them in the future (Table 6, supplemental material).

These findings suggest that the use of sex toys is widely desired and practiced by people with disabilities. The top three reasons participants stated for using sex toys were that sex toys "enabled them to discover new ways of playing and new sensations," "amused them a lot," and "enabled them to experience very pleasant genital sensations that they would not otherwise have been able to experience." However, limitations in genital sensitivity and difficulty in using sex toys without assistance were the main factors that prevented some respondents from using sex toys, even when they desired to. These findings suggest that Lovewear can be a desirable support in enhancing one's well-being by building self-confidence and awareness, without being a replacement for human contact.

Our focus groups helped us to gain insights about the sexuality of people with disabilities and data to integrate into the survey. As Lovewear is intended for female wearers, only females with motor disabilities were recruited for the focus groups. Participants in the first group included two women with spastic quadriplegia and one with osteogenesis imperfecta, while participants in the second group included two women with spinal muscular atrophy and one with muscular dystrophy. These focus groups also served as an opportunity to engage with potential Lovewear users and were conducted as part of a participatory co-design approach to define the product requirements (Fig. 2) [21].

Following these focus groups, we defined the following features as requirements for a sex toy targeted to people with disabilities:

it must be easy to use without external help,
it must enable orgasm,
it must be easy to use with a partner, and
it must be remotely controlled.

Four user scenarios and four personas were identified based on the data collected. Lovewear can be used individually or with a partner, by users with or without motor impairments, and eventually with the support of a caregiver.

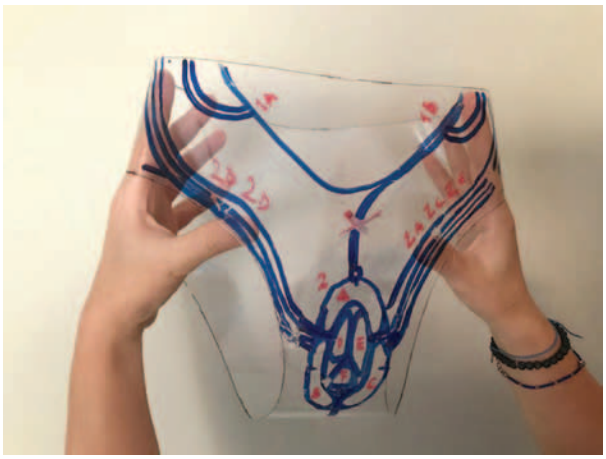

Fig. 2. The prototype used during the focus group for the development and the co-design phase. (© Emanuela Corti and Ivan Parati. Photo: Ivan Parati.)

Among our findings, we identified the need to consider other erogenous body parts, voice control as an option for further development, and the possibility of replacing the pillow with other kinds of interfaces.

LOVEWEAR'S OBJECTIVES

Lovewear (Fig. 3) is a cognitive and educational tool that empowers movement-impaired people by giving them autonomy to explore their own bodies through an interface pillow that through rough gestures controls the underwear with inflatable actuators, characterized by different patterns that stimulate various erogenous zones of a female wearer.

Most people in the target group could operate rough circular gestures or pressure on the pillow with their hands, which could also be pressed by the head or other body parts (feet or knees) depending on the individual's abilities (Fig. 4). Others with fine movement abilities and lack of limb mobility might control the actuators with their fingers from their mobile phone through an application (yet to be developed).

We aimed to create a wearable device that could be worn with or without external help, activated and used independently at any time. Lovewear is aimed at generating the natural sensation of a tactile movement on the skin's surface through soft robotics. The effect is achieved through miniaturized pumps and solenoid valves to precisely direct and control airflow through a matrix of isolated textile chambers.

The use of soft robotics provides several advantages over conventional robotics, especially soft structures that are more suited for safer human interaction and can potentially reduce mechanical complexity [22]. Although pneumatics with a hydraulic system has been among the most utilized forms of actuation since the beginning of soft robotics in the 1990s [23], their implementation with a textile-based solution is a recent direction [24]; while actual manufacturing methodologies still rely on elastomer materials there are clear indicators of the advantages of textile-based pneumatic systems [25].

Pneumatic artificial muscles and bellows are actuation devices that convert fluid pressure into linear and unidirec-

Fig. 3. Lovewear prototype. At the top is the pillow interface, and at the bottom is the underwear garment. (© Emanuela Corti and Ivan Parati. Photo: Raoul XV.)

tional force and motion. There are many different methods of fabricating pneumatic artificial muscles (also known as McKibben actuators) depending on the desired specifications and intended application. Although they have been consistently developed over decades and are available in commercial versions from several suppliers [26], they were not considered for the actual project, in which we aimed to achieve movement by exploiting the dynamics of nonstretchable fabrics' geometric deformation and integrating the fabric actuators as seamlessly as possible into the garment itself. For those purposes, the heat press method was employed to fabricate the actuators to minimize the thickness of the device and explore embedded hinges to control motion [27].

However, the general method is based on silicon molds, which makes the process expensive and not appropriate for industrial production. Within our collaboration with Fraunhofer we simplified the manufacturing process through thermoplastic coated and textile-based soft actuators to reduce the time and cost of production of the components and therefore push the final product in a more sustainable, affordable, and democratic direction.

The inflatable components are positioned in the main body of the underwear garment, which is produced with a warp knitting technology that allows seamless pockets.

SOFT ACTUATOR DESIGN

The Lovewear project pursues a novel concept for implementing haptic stimulation through the development and use of soft actuators embedded in knitted underwear. The further advantages of the textile-based approach are low weight, extremely low profile at atmospheric pressure, high force/weight ratio, and simple, rapid production. In addition, the method enables sustainable manufacturing (through reduction of material waste, avoidance of chemical additives, and reparability) as well as implementation within the urban manufacturing concept (local value chain from design through production to integration and sales from batch size 1, with potential for scalability for mass production).

The key challenge in creating soft actuators is the development of controllable soft bodies that require new materials, designs, and processing technologies to exploit the full potential of soft robotics [28].

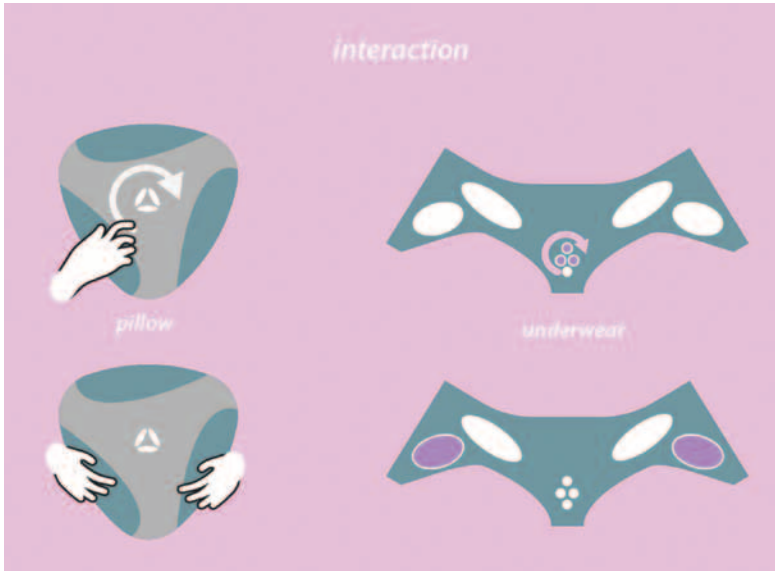

Fig. 4. Interaction of pillow and underwear: rough gestures on the pillow activate different actuators in the underwear. (© Emanuela Corti and Ivan Parati)

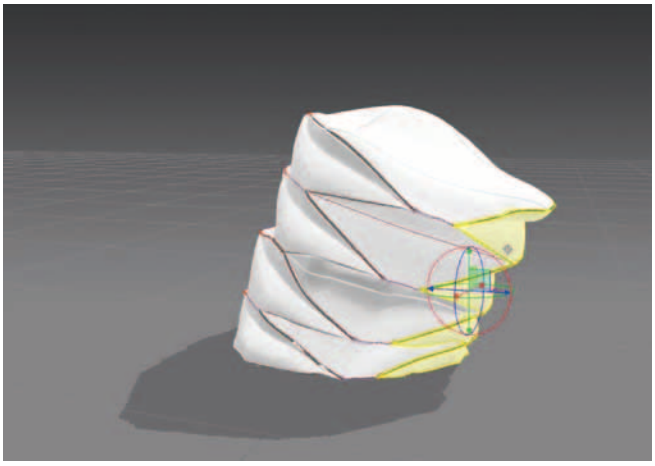

Fig. 5. Digital models were made to pretest materials and inflation. (© Ivan Parati)

The recent emergence of virtual fashion commercial software tools has given designers the chance to explore fabrics' inflation dynamics with sufficient reliability before investing time and resources in physical prototypes, thereby significantly decreasing the number of iterations required (Fig. 5).

MATERIAL TESTING

Since fabrics are open-pored materials, they need an air-impermeable coating, such as a thin film made of thermoplastic polyurethane (TPU). In our experiments (Fig. 6), we used textiles with pre-applied TPU coatings, but we also laminated TPU films to fabrics that were up to 55% elastic. In addition to canvas fabrics based on polyamide and polyester, we also examined slightly stretchable jersey fabrics as textile substrates.

Two or more layers of thermoplastic-coated textiles are built up in such a way that a bubble is formed through which compressed air can flow and thus cause local deformation. There are four options for structuring the cavities: selective sealing by ultrasonic plastic welding; hot air sealing [29]; laser welding [30]; or masked thermal bonding. With a view to the broad availability of the technologies and process transfer to the industry, we have focused our experiments on ultrasonic plastic welding and the lamination processes that are already widespread in the textile manufacturing industry.

With continuous ultrasonic welding, heat is generated at the joining zone by means of frictional energy, and the thermoplastic materials are thereby locally converted into a molten state. With application of a process pressure at the same time, the joining partners are brought closer and quickly solidify again after the ultrasound is switched off. The advantages of the process are the short process time and solely local energy input, which means that elastic textiles with lower melting temperatures can also be processed. However, in our experience, ultrasonic welding is only suitable to a limited extent for the manufacture of textile-based soft actuators. For one, the result of a weld seam depends strongly on the skills of the operator, since it is carried out manually in the same way as sewing a seam.

For these reasons, we switched to lamination during the project. During lamination, thermal energy is released over the entire heating surface. To prevent the inflatable structures from sticking together after the lamination process, we applied water-soluble polymer films made of polyvinyl alcohol (PVAL) in the center of the material stack where the air channels and cavities are located. Following Connolly [31], our idea was to dissolve the PVAL films after lamination by immersing them in water and thus to selectively structure the material composite. Unfortunately, in our experiments, the PVAL films could not be subsequently dissolved in water. A problem here is the small area of water contact due to the unfavorable ratio of thin film width to depth. We

Fig. 6. Welding tests. Various shapes and structures have been considered to support pressure and movement. (© Emanuela Corti and Ivan Parati. Photo: Raoul XV.)

Fig. 7. Final lamination tools and sample produced. (© Emanuela Corti and Ivan Parati. Photo: Raoul XV.)

therefore switched to using a template for masked thermal bonding. A tool made of 6-cm-thick aluminum sheet was therefore structured by a water jet cutting process to create a lamination mask. The tool was placed between the heating plate and the stack of material so that the areas where the material is in direct contact with the aluminum mask would adhere to one another during lamination, but no adhesion would occur where there were openings in the mask. With this approach, we were ultimately able to manufacture the textile soft actuators.

By searching for lamination parameters, we found suitable heating temperatures, process times, and process pressures with which complex patterns with a minimum distance of up to 2 mm can be reliably produced for all kinds of coated textiles. The soft actuators produced in this way were then qualified with a compressed air test of 8 bar. Figure 7 shows several samples produced for the actual prototype with their lamination tools while Fig. 8 focuses on the central pad.

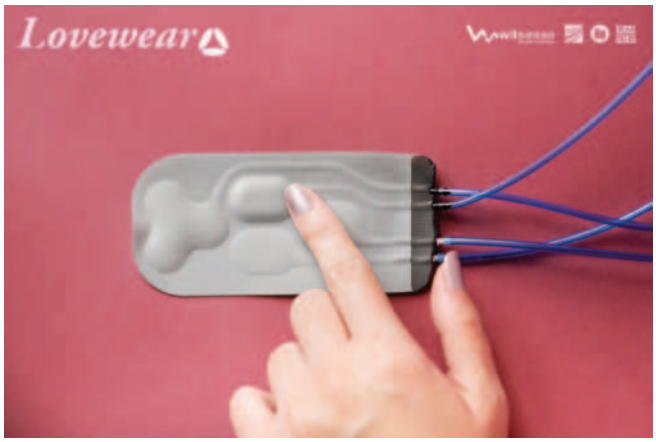

Fig. 8. Central pad. (© Emanuela Corti and Ivan Parati. Photo: Raoul XV.)

WHAT WE HAVE LEARNED

Soft robotics is still finding its way to commercial applications, and one of the main barriers is to be found in the gap between prototyping and mass manufacturing techniques. The mass production of these devices poses several limitations in terms of design complexity. Inflatable commercial products are generally mass manufactured by high frequency, ultrasound, or hot welding using metal templates as tools and woven or nonwoven thermoplastic sheets as principal materials. While the equipment constitutes a consistent investment, the price per piece is relatively low. The techniques refined during our research fill this gap between prototyping and actual manufacturing in such a way that the prototype is very near to the commercial object at a fraction of the cost per unit. Moreover, virtual prototyping can significantly shorten development costs and time. These findings help contain the final product cost, making it more accessible to a wider audience and giving a chance to produce small prototype batches that can be tested during the development phases.

The final prototype hasn't been tested yet. The aim is to collect more funds to produce multiple models to be tested with the support of some focus group participants who already gave their availability. While the project is focused on female users, further exploration will consider the complex dynamics of male genital stimulation.

Acknowledgments

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In 2017, they co-founded Witsense, intending to develop sensible innovative products and services, and design elements that can improve living conditions, favoring social inclusion through the promotion of independence. Their work received international recognition and several European grants.

CHRISTIAN DILS *joined the Systems on Flex group at Fraunhofer IZM, Berlin, in 2007 and now works as a researcher and project manager, as well as head of the TexLab laboratory. His research focuses on the development of stretchable and textile-integrated electronics, particularly concerning substrate manufacturing and interconnection technologies.*