Wear-to-Care. Co-designing the Next Wave of Open Wearables in the Healthcare Sector

Massimo Bianchini[1], Patrizia Bolzan[1(✉)], Barbaras Parini[1], Stefano Maffei[1], and Filippo Cipriani[2]

[1] Department of Design, Politecnico di Milano, Milan, Italy
patrizia.bolzan@polimi.it
[2] Sanofi Genzyme, Milan, Italy

Abstract. The paper explores the topic of design, materialization and release of open source wearables that can increase awareness about the mental, behavioral and physical conditions of people with health impairments. The first part, which is based on literature review, investigates the design of healthcare wearables connected to the emerging phenomena of open and user innovation. The second part describes the whole process of design and materialization of DermAware, an open source "experiential" wearable developed within the project Distributed Design Market Platform (Creative Europe Programme) and specifically conceived to increase the social awareness on a pathology such as Atopic Dermatitis. The final part defines an operational framework to design open source wearables, evidencing the process - from design to materialization – and the main critical aspects and opportunities related to the development of "experiential" devices. The conclusions of the paper identify a possible field for designing healthcare wearables called "Wear-to-Care".

Keywords: Open innovation · Interaction design · Smart wearables · Atopic dermatitis · Disease awareness · Patient advocacy

1 Introduction

Nowadays, wearables such as smartbands, wristbands, and smartwatches are designed to capture and monitor human activity parameters and to display such data and information. Characterized by a rapidly accelerating technological evolution, the market of smart wearables is constantly growing, and their fields of application are constantly expanding (Fig. 1). Within this emerging global market, the market share represented by smart devices dedicated to diagnostics and medical treatment is also growing. Finally, a specific segment dedicated to healthcare consumer wearables is beginning to appear.

On an industrial level, design and production of consumer and specialized wearables is currently characterized by three main aspects. Firstly, the majority of these smart devices are conceived with a top-down design logic and therefore not designed through explicit co-design and user processes. These tools are designed to enable personal use

P. Perego et al. (Eds.): ICWH 2020, LNICST 376, pp. 122–138, 2021.
https://doi.org/10.1007/978-3-030-76066-3_10

but cannot be customized according to personal needs, different from those for which they are conceived. Secondly, these devices are equipped with industrial components and "proprietary" software far from open source logic applied to design, hardware and software. In practice for these products there is no release of digital files and code. Finally, the majority of consumer wearables can record data to provide basic diagnostics (e.g. heartbeat, pressure, temperature, sleep cycles,…) while medical wearables are mainly conceived for a professional use. On the contrary, are not so common cases of wearables designed to release physical inputs, enabling and stimulating users to have alternative sensorial experiences. Irrespective of the prevalence of the disease, there is the need for new experiences enabling new forms of health literacy, disease awareness, and patient advocacy. Currently, this need is weakly satisfied by smart wearables on the market since they are not co-designed with patients.

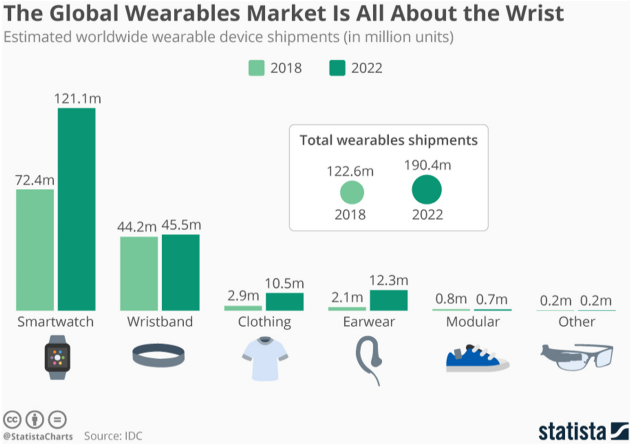

Fig. 1. The global wearables market is all about the wrist (source: Statista)

Starting from this assumption, the paper aims to explore wearables designed to improve physical and social interactivity needs of people with disabilities or health impairment - which are influenced by *open* and *user innovation* cultures - developed through a co-design approach, manufactured through open and distributed production processes.

Through the design perspective, the paper defines as "Wear-to-Care" this area of participatory and bottom-up innovation for the development of smart wearables, proposing to address to the following research questions:

1. *What are the key elements that define Wear-to-Care as an approach and innovation process?*
2. *What functional, performance and perceptive characteristics do Wear-to-care wearables have or must have?*
3. *What is the process of design-production and distribution that characterizes Wear-To-Care devices?*

The paper aims to create an initial framework on the design of open source "Wear-to-Care" wearables, focus on a specific case study related to a pilot research initiative: DermAware, an open source device specifically designed to increase the social awareness about the mental, behavioral and physical conditions of people with Atopic Dermatitis (AD), still underestimated today [9]. DermAware has been developed in 2018 within FabCare, an experimental initiative part of the Distributed Design Market[1] project (Creative Europe Platform Programme), thanks to the collaboration, in Italy, between Sanofi Genzyme[2] and Polifactory, respectively the specialty care unit of Sanofi and the Fab Lab of the Politecnico di Milano. DermAware is an open source wearable device that does not track or capture information but, on the contrary, faithfully simulates the uncontrolled sensation of constant itching that is the hallmark of AD. The first part of this paper combines literature review and a short selection of case studies in order to explore the evolution in the design of healthcare wearables connected to the phenomenon of patient innovation and supported by the democratization of open source design and distributed digital manufacturing [2]. The second part of the paper describes the whole process of designing and materializing DermAware, from the first concept, to the subsequent reflections on the aspects of design and technology, up to the usability characteristics connected to the pathology and the desired user experience. The third and final part attempts to elaborate a framework highlighting all the critical aspects and opportunities related to the development of devices such as DermAware, within the emerging field of "Wear-to-Care".

2 Healthcare Evolutionary Paths and Implications for Wearables Design

A multiyear research conducted from 2017 to 2019 by Politecnico di Milano[3] entitled MakeToCare[4] (MTC) [3, 4] has explored the emerging socio-technical transformations within the healthcare sector. MTC describes an area of convergence that begins from the interaction between the official healthcare sector, making and new manufacturing and patients as carriers of innovation needs. The research, in fact, begins from the assumption of a deep transformation of the contemporary healthcare sector. A preliminary literature review highlighted the following research topics:

[1] distributeddesign.eu.

[2] www.sanofigenzyme.com.

[3] The research has been promoted by Fondazione Politecnico and Sanofi Genzyme and coordinated and developed by Polifactory the makerspace FabLab of Politecnico di Milano (www.polifactory.polimi.it).

[4] MakeToCare (www.maketocare.it) is a research initiative that was born as a spin-off of the first edition of the homonymous contest organized in 2016 by Sanofi Genzyme, on the occasion of the European Maker Faire in Rome. MakeToCare aims to identify, map and represent an emerging ecosystem made up of innovative patients, independent researchers, research institutions, startups and new entrepreneurs, makers, and laboratories for digital manufacturing that work on the development of concrete design solutions capable of improving daily life and the health of people living with disabilities. The research, still ongoing, has mapped 180 subjects and 150 solutions developed in Italy.

- *healthcare tailored to an aging population.* It analyzes aging from the perspective of its social implications on an individual and collective levels (impact on patient and caregivers and social sustainability of welfare);
- *healthcare for the new generations (between prevention and prediction).* It concerns the digital transformation of healthcare, the virtualization of medicine, new forms of health literacy, and new levels of knowledge and awareness of the human body from external manifestations to genetic structures;
- *healthcare on a metropolitan scale.* It concerns the increasing concentration of population in the cities seen from the new perspectives of citizens-patients and the perspective of the healthcare system;
- *technologically enabled and enhanced healthcare.* It concerns the technological development that 'enhance/augment' persons and products-service systems for care changing the body's limits and barriers, and extensions of the objects and care environments. In that sense, disability can be 'simply' considered as a gap between the person and the environment, a situation that can be reduced or closed with design-focused interventions.

Starting to consider this general framework of transformation, a relevant aspect can be considered: the role of the patient and the impact generated by his engagement in an extended and inclusive way. It is the patient (r)evolution: from *human factor* to *human actor* within innovation processes. Starting from this statement, we can identify grassroots innovation models where the patient is the activator or where there is an open and participatory activity between patients and other subjects with different expertise. Moreover, these evolved forms of user participation foster the rise of the *patient-innovator* and *user-driven healthcare* [5–7]. Platforms like patientlikeme.com, patientinnovation.org, and careables.org are initiatives that operationally and socially support patient innovation. Patients were for a long time considered primarily the passive recipients of the processes of innovation proposed by public and private healthcare systems or by healthcare sector companies, i.e. the providers of products and services.

Nowadays, cultural globalization and democratization of enabling technologies make people increasingly informed and socially connected to assert themselves in different fields and sectors. A greater knowledge, combined with growing awareness and supported by the new production possibilities offered by digital manufacturing such as personal fabrication, have gradually transformed the patient not only into an element at the center of the innovation process, but often the trigger of the whole process. This is the so-called Patient Innovator (PI), an actor who actively works in the field of designing and materializing products and services to solve a personal problem, often self-producing solutions to improve his condition. Often the new wearables are born precisely in similar contexts. It is undeniable that the development of wearable devices in the healthcare sector is following two parallel directions that are destined to converge. On one hand, there are devices designed and used for purely medical purposes, with functions ranging

from pharmacological therapies to specialized biometric monitoring (such as insulin pump, artificial pancreas, cardiac holter), whose purposes from diagnostics to tests to postoperative follow-up. On the other hand, there is an evolution of wearables for digital well-being, equipped with a number of sensors capable of performing an increasingly accurate biometric monitoring on the state of health and well-being of the person, then returning it in the form of raw data or aggregated information (even alerts) thanks to dedicated smartphone applications. A clear example in this direction is represented by the evolution of the Apple Watch [8].

Next to "top-down" wearables, born in the industrial sector with declared commercial purposes or within research centers as tools of investigation and analysis, we are witnessing the progressive appearance of wearables that we might better define as "bottom-up". These are often devices born from the intuition of subjects (individuals or small design teams) in response to specific needs (own or others), as shown by the MTC research, which since 2017 has investigated open and user innovation (especially bottom-up) within the healthcare sector in Italy. The MTC research shows how more and more often we are witnessing the development and implementation of wearables capable of supporting users in better managing pathology and/or disability. Two specific cases (on a total of 150 initially mapped) have been extracted from MakeToCare to support this analysis: ABBI K and Sensewear. Although these two wearables are very different in terms of design process, scopes and subjects involved, in both cases they have been designed to release data and information not only in visual form, but also through physical inputs, providing a sensory experience to the user. On the one hand, the Italian Institute of Technology (IIT) project developed starting from a European research aimed at developing devices for the rehabilitation of subjects with visual impairment. On the other hand, the project developed by a young startup, Witsense, born from the union of the technological skills of a company specialized in wearable biomedical systems with the vision of a design studio.

ABBI K[5] is a kit for the assessment and rehabilitation of children with visual impairments. Thanks to a sound bracelet, kids can associate movements with acoustic feedback, which provides them with the opportunity to perceive their movements in a more appropriate way and develop skills to move and play within the space. Sensewear is an inclusive collection of garments and accessories that emphasize the use of senses. It is in fact a sensitized set of garments clothing line that, reacting to changes in some vital parameters, allows children with autism and/or communicative-relational difficulties to communicate their moods and reach a condition of comfort. The Sensewear collection is inspired by therapies applied to Sensory Processing Disorders and developed with the technical support of therapists assisting people affected with autism.

[5] ABBI K is developed by Unit for Visually Impaired People of IIT (www.iit.it/research/lines/unit-for-visually-impaired-people); the main aim of the Unit is to early identify spatial impairments that impact life of visually disabled people and build innovative solutions to prevent the risk of developmental delays.

In terms of maturity, ABBI K has completed the testing, verification and final implementation phases and is preparing to become a commercial product in all respects, distributed via spin off by the Italian Institute of Technology itself; Sensewear has concluded the second phase of prototyping. The last version of the collection includes SenseMe, a smart t-shirt that monitors heartbeat, breath rate and movement, sending data to an application that records sessions and triggers other garments' functionality according to adjustable values. Two pieces from the previous collection have been further developed and upgraded with tech.

Within this scenario is precisely placed the DermAware project, a wearable device which integrates an unprecedented concept. In fact, DermAware combines the common capability of many wearables in providing feedback to better manage a pathology with a new dimension related to the awareness and communication of the pathology, not only by the "user-patient" but also and above all by the entire formal and informal caregiving system surrounding him (Fig. 2 and 3).

Fig. 2. *Abbi K* (photo credit: L. Taverna © 2017IIT)

Fig. 3. *Sensewear* (photo credit: Witsense srl).

3 The DermAware Project

3.1 Designing for the Atopic Dermatitis

General definitions provided by national patient association like Associazione Nazionale Dermatite Atopica (ANDeA, Italy) and National Eczema Association (NEA, US) describe Atopic Dermatitis as the most common type of eczema. AD is a chronic skin disease characterized by intense itching, dry skin, the appearance of diffuse redness and blisters on different areas of the body. It is a non-contagious chronic-frequent inflammatory dermatosis that alternates periods of exacerbation and remission, mainly affecting hands, feet, inner fold of the elbow and the rear fold of the knees, wrists, ankles, face, neck and chest, but also present around the eyes. Although its onset is often associated with the first years of life, with an incidence that is around 10–20% of children and 2–8% of adults (in most countries of the world) [10–12].

AD has a strong impact on quality of life in terms of recurrent skin infections, sleep disturbances, social relationships and work productivity. According to literature, children with AD present emotional-relational difficulties: low self-esteem, behavioral and attachment disorders. Adolescents and adults with AD present severe difficulties in interpersonal relationships (also caused by bullying phenomena), personal insecurity, and increasing stress levels, anxiety and depressive symptoms [12–14]. To date there is no definitive cure capable of leading to a complete recovery from AD. Patients must therefore "learn" to coexist with this pathology and manage it with daily tricks that can help alleviate its symptoms and prolong the phases of remission. Special soap-free products, appropriate clothing and the systematic use of emollient creams formulated specifically for sensitive skin are all elements that can mitigate the discomfort of those living with AD.

Fig. 4. Patient with Atopic Dermatitis of the inside crease of the elbow (source en.wikipedia.org/wiki/Atopic_dermatitis)

Born in Boston as a pioneering biotech in the early '80s, Sanofi Genzyme (SGZ) became in 2011 the specialty care division of Sanofi group and is conducting research and development in many therapeutic areas, including Atopic Dermatitis. Sanofi Genzyme has developed over the years a patient-centric approach which also combines Open Innovation and Responsible Research Innovation. For this reason, SGZ is very active in co-designing pilot initiatives with patient associations, patients, caregivers and independent innovators, universities and Fab Labs to empower knowledge and capabilities of patients affected by AD and other diseases. The goal of these initiatives is to increase the level of awareness about this pathology and to find new solutions, even beyond the pill, that can improve the quality of life. With that goal in mind, Sanofi Genzyme Italian affiliate took part to ICARO UNIMORE[6], an entrepreneurial education program promoted by University of Modena and Reggio Emilia. ICARO UNIMORE is an experimental project focused on entrepreneurial education in which multidisciplinary teams collaborate with researchers to develop six-months project-works aimed to provide innovative solutions to real challenges. In 2018, a multidisciplinary group of young student and innovators - Nicolò Bisi, Nur Eral, Mattia Fantoni, Volodymir Hladysh, and Maria Benedetta Maffezzoni[7] - supported by researchers, medical specialists and patients collaborated with SGZ to develop a workstream for rediscovering AD and empower patients. The DermaTrack concept was conceived to understand AD experience in order to develop a new generation of Patient Support Program (PSP) aimed at ameliorating the relationship between patients and dermatologists. Patients complained about the difficulties to

[6] See www.unimore.it/ICARO/.

[7] Nicolò Bisi, Nur Eral, Mattia Fantoni, starting from the results of the preliminary analysis have actively participated in designing and prototyping the first version of the DermaTrack.

summarize during check-up visits about the real burden of disease. The DermaTrack project has been divided into two parts: (i.) analysis of patients' needs and behaviors, (ii.) design and prototyping of a concept for a new product-service. Patients' needs and behaviors were initially documented through interviews of 50 patients[8]. 70% of respondents are under 35 years old and 60% are women. Regarding the degree of severity of the disease: 20% declared mild AD, 50% moderate AD, 30% a severe AD. The sample has later been expanded to 159 patients, though online questionnaires. The daily difficulties encountered were partly physiological, closely related to pathology (such as excessive itching, burning sensation, difficulty in sleeping and resting) and partly related to its social stigma, both in the private-family and public-professional sphere, with repercussions on the emotional wellbeing. Itching turns out to be a key element. Although it represents one of the main symptoms of this pathology, it is in fact not measured according to objective criteria. Patients describe the itch intensity using a 0 to 10 scale.

Emerging from the survey, itching and scratching were often the cause of misunderstandings and communication difficulties between the patient and their formal and informal caregivers (medical staff, family and friends). Itching was often misinterpreted as poor personal hygiene. This communication gap is increasing the sense of frustration and inadequacy in the patient himself. Through the interpretation of this analysis it is possible to outline some key points necessary to (co)design feasible solutions: (i.) helping the patient to feel understood and accepted; (ii.) assist the patient in effectively communicating the severity of symptoms to doctors/family members/friends; (iii.) increase the knowledge of AD in the population (Population Awareness).

In addition, through this interpretation, the relationships between the various stakeholders (doctors, institutions, caregivers and general population) and patients can improve, leaving room for empathy, better collaboration and, ultimately, acceptance. Moreover, the analysis evidenced the importance of active listening and sharing. And it is mainly thanks to the re-evaluation of soft skills that we have understood how fundamental it is to give a voice to the patient with AD, whose disorder is often not considered severe enough and not impacting in daily life. We believe patients feel not included because the disorder is not objectively transferable: an objective measuring system must be created that can measure and transmit the impact of the pathology. This is true for AD but can be applied to many other conditions.

Nowadays, dermatologists measure the multidimensional impact of AD by assessing: lesions (EASI Index- Eczema Area and Severity Index), pain (VAS), itching and sleep disturbances (NSR scale - Numeric Rating Scale), quality of life (DLQI - Dermatology Life Quality Index), anxiety and depression level (HADS) and the patient benefit index (PBI). However, patients do not have immediate tools to self-evaluate the severity of their pathology which has a dynamic nature. Therefore, dynamic and objective measurement of itching is a topic that is taking on a relevant dimension even among dermatologists who might be interested in monitoring disease activity through longitudinal quantification of the itch (Fig. 4).

[8] 60% of the sample interviewed by telephone and 40% interviewed in person.

3.2 Origins and Development of DemaTrack

Starting from patient quotes, the students further investigated living with AD. For 84% of all respondents (89% in moderate and severe cases) itching is the most problematic aspect of AD, more than the extent and severity of the lesions. The data on the frequency of scratching (Fig. 5) is emblematic. 42% are not even able to make a hypothesis while 22% report to scratch more than 120 times/hour or more than 2880 times per day. Itch is responsible for sleep difficulties (more than 120 days in 30% of responders) as well as disturbance in daily activities (more than 120 days in 98% of responders).

This shows how it is impossible for a patient to keep a diary updated manually (and how it is necessary to automate the process) and how the pathology generates a compulsory and uncontrollable scratching that is difficult to hide in public and be ignored by other people. 65% of respondents complain that it is very difficult to transfer effectively the impact of the disease to their doctor. About 40% of patients said they were very interested in solutions for itch monitoring while 34% already tried in the past to keep a diary to monitor the course of symptoms.

All these aspects generate problems in terms of communication, trust, and self-esteem with those around you: not only doctors but also family and friends. The first prototype of the DermaTrack wearable has been developed by hacking and reprogramming an existing *smart band*, and connecting it to an app, allowing patients and specialists to visualize data and information. Basically, the bracelet allows the patient to quantify the itch in an indirect way: counting the frequency and the intensity applied by patients to seek itch relief through the action to scratch.

Together with other parameters such as degree of skin hydration hours of sleep, UV index, weather, humidity, quantity of pollen/allergens in the air will support dermatologists in a multidimensional monitoring, extending the observation beyond the test itself. DermaTrack is conceived to be a discreet personal wearable, indistinguishable from other devices, both for users and observers. The manually adjustable parameters are instead the self-reported daily mood, foods ingested, if different from standard diet, and a space for personal notes.

Another key point missing with respect to the needs analysis is solved: through DermaTrack, a person affected by AD will in the future have a more accurate detection system that will improve individual knowledge of the pathology as well as the relationship with the dermatologist. The students also thought about social acceptance aspects of pathology: to make everyone experience what it means to live for a while with AD. The idea was to have a "play" function: AD patients can borrow their DermaTrack to a healthy individual. DermaTrack will then faithfully reproduce itch intensity and frequency recorded in the AD Patient.

However, due to the complexity to develop simultaneously all these functionalities, it took form the idea of developing a second, simpler and stand alone, device capable of generating this type of experience together with the makerspace of Politecnico di Milano (Polifactory), in an open innovation approach: the *DermAware* project.

The opportunity to study the broader implications of leveraging itch as disease awareness came up by participating in a call for ideas promoted by Polifactory, the Fab Lab and makerspace of Politecnico di Milano, as part of the first year of the FabCare initiative, within the *Distributed Design Market Platform* (DDMP), that is a project funded by

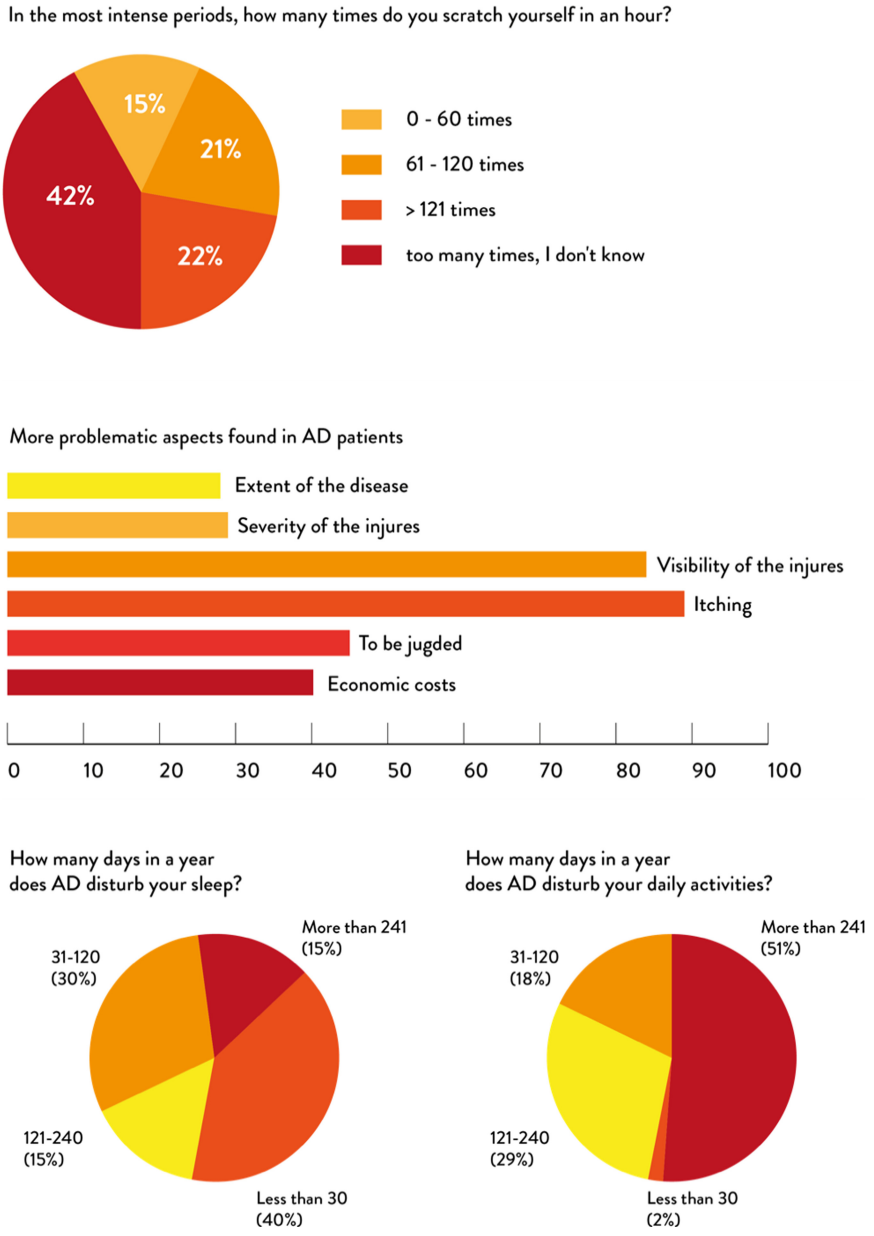

Fig. 5. Data on aspects connected to *Atopic Dermatitis* (base: 159 answers; source: DermaTrack project Report)

Creative Europe Program to implement the global network of Fab Lab promoting and improving the connection between makers and designers with the European market. The premise behind FabCare [1] is that nowadays, types of products such as aids and prostheses can be designed using open source knowledge, software and hardware, and then be materialized in Fab Labs combining makers' skills with digital manufacturing technologies. Starting from this logic, a multiplicity of different solutions can be conceived, intertwined and implemented answering the needs of prevention or care for everyone. FabCare is an experimental initiative created to stimulate designers, makers and independent innovators to design open source products for healthcare that can be distributed through digital platforms and materialized in Fab Labs. Therefore, FabCare's challenge aims to demonstrate how designers, makers and independent innovators – also interacting with patients, caregivers and their associations – can concretely design, produce and distribute open source healthcare solutions with a real market potential.

The challenge of FabCare is to demonstrate how an open source approach concretely offers advantages for the patient, for the health care system and stimulates the production system, digital manufacturing in particular.

This challenge is based on an emerging discussion both in the scientific world and in communities of independent innovators (e.g. makers) about the effectiveness of the current approach to the development of consumer wearables, ranging from sports to healthcare. An emerging and diversified scientific literature is studying comparative models on the accuracy of consumer wearables [17], verify the effectiveness of the sensors used [16] reflect on privacy and security aspects in relation to shared use of biometric data [18], identify the limits on human empowerment achievable through these devices [15]. Independent innovators not only think and work on how to democratize design and fabrication of the consumer wearables but are also thinking out-of-the box on how to design "anti-wearables" trying to move tracking functions from wearable devices to common objects that interact everyday with the people.

Taking into account these emerging opportunities and critical issues, the advantages offered by open source in the development of consumer wearables on which the development of DermaTrack and DermaWare projects is based are:

- to develop totally customized solutions that do not constitute an alternative to the existing consumer wearables market but create an additional market option;
- to develop different versions of the same solutions in order to satisfy simultaneously several purposes related to a pathology such as diagnosis, monitoring, treatment, learning, awareness, etc.;
- to build peer-to-peer design and production platforms, where patients, specialists, designers and manufacturers can collaborate in the design and implementation and overall management of design solutions (hardware, software, design and usability);
- to use design and manufacturing resources and tools that allow patients and specialists to access these solutions locally (one-off or small series parts, specific components to repair, modify or upgrade existing versions) while taking advantage of the possibilities offered by digital fabrication and at the same time respecting its limits;
- to enable the replicability, transferability and possible scalability of a solution if it is useful for multiple patients affected by the same pathology, if it is useful for patients

affected by other pathologies, if it needs to be produced on a large scale by engineering it for industrial production.

3.3 Design, Materialization and Showcase of DermAware

The new project of the digital bracelet has been named DermAware, just to emphasize the desire to shift the focus more on the phase of awareness of the disease experienced by people with atopic dermatitis. It is an educational digital device conceived to make people aware of the effects generated by the co-existence with atopic dermatitis. It simulates the annoyance generated by pruritus, typical of this pathology, at variable intervals and with different levels of intensity. Likewise, the presence of LED lights on the wearable that light up randomly, serves to attract people's attention by simulating what happens to a patient with AD when scratching in public, unintentionally.

In this way, DermAware can be used by patient associations, such as ANDeA, or in schools and workplaces (where there is a compelling body of evidence of bullying and discrimination versus AD patients) to organize sensibilization and educational initiatives. Therefore, the choice has been made to develop a hardware from scratch, which can be realized with the machines typically present inside the Fab Lab, made up by: a custom electronic board[9], a chassis made with Stereolithography (SLA) 3D printing technology and a bracelet created with Fused Deposition Modeling (FDM) 3D printing technology (Fig. 6).

The authors, Nicolò Bisi, Nur Eral, and Mattia Fantoni, were in charge of developing a new open-source code, while Polifactory's contribution was to design and build the whole performing hardware, and to support the development of the user experience that DermAware was supposed to offer. Instructions and files to create your DermaAware can be downloaded from the distributeddesign.eu platform and the Polifactory's website[10]. Thanks to the development provided by Polifactory in terms of usability and product design, and by a research group from the Department of Electronics, Information and Bioengineering (DEIB, Politecnico di Milano)[11] concerning the electronic design and debugging of a custom PCB, it is remarkable how the idea behind the project has finally had the strength to be communicated in an effective and coherent way. In fact, from the point of view of electronic hardware production, it has been possible to obtain an open-source electronic board of very small dimensions - which is essential when working in the wearable field. As far as the formal design of the device is concerned, it has been chosen to work in a complementary way: the electronics has been completely incorporated into a smoothly sculpted body, with a surface texture whose function is to amplify the punctiform perception of the vibration on the user's skin. DermAware is an object designed without display and buttons - except for the power-on one - just to not distract the user from the haptic dimension of the experience. Thanks to the support

[9] Designed and made thanks to the collaboration with Angelo Geraci, Nicola Corna, Fabio Garzetti, Nicola Lusardi belonging to the Department of Electronics, Information and Bioengineering (DEIB).

[10] Direct link: www.polifactory.polimi.it/polifactory_progetti/ddmp-fabcare?lang=en.

[11] PCB designed by Angelo Geraci, Nicola Corna, Fabio Garzetti, Nicola Lusardi (DEIB Department, Politecnico di Milano).

Fig. 6. The prototype of DermAware (open source project downloadable at: www.polifactory.polimi.it/polifactory/fabcare/ and distributeddesign.eu)

provided through the Fabcare initiative, DermAware has become a functioning prototype, presented to the public at the Sanofi Genzyme booth during the European Maker Faire in Rome in 2018[12] where the most promising open source healthcare solutions on the Italian scene of the moment were shown.

[12] Every year, the European Maker Faire Rome registers more than 120.000 visitors.

4 Defining the "Wear-to-Care" Approach to Design Smart Wearables

The combination of DermaTrack and DermAware projects brings out two qualifying aspects of the design area that we have named Wear-To-Care in this paper. The first aspect concerns the possibility to expand the "functional" dimension of wearables - the biometric measurement - adding the open source dimension of "experimental" and "experiential", currently little explored by wearables on the market. The combination of these three dimensions is what characterizes the originality of "Wear-to-care" products. The second aspect - strongly related to the first - concerns the innovation generated by the experiential dimension of wearables that allows to think "out-of-the-box" exploring unusual and unexplored functions or purposes that go beyond biometric monitoring and measurement. In this way the "Wear-to-Care" is characterized as an innovative approach to the design of wearables for the healthcare sector.

In particular, reflecting on the development of the DermAware project, it is possible to extrapolate some general rules to model a design process for new open source wearables with "experiential" functionalities. The first phase is related to:

- set-up a basic knowledge framework on the pathology through the acquisition of signs and symptoms. and disease management by healthcare specialists;
- develop in-depth and on-field knowledge related to the change of life dynamics triggered by illness at an individual, family and social level. This knowledge can be derived from the patient's personal experience, from the interaction with family members and caregivers and with the relevant environment. Such data can be later integrated and systematized on a larger scale by interacting with patient associations;
- combine the knowledge on the disease (or disability) with those related to the patient's habits and condition, and with his declared need and willingness in order to develop a wearable that works to improve the quality of life, bridge a physical, cognitive or relational gap and ultimately reduce social stigma.

In the design phase two complementary options can be considered: (i.) to design the "functional and operational" version of the wearable, in order to meet the personal needs of the patient (or a group of patients); (ii.) to design the "experimental and experiential" version of the wearable in order to allow people who do not have the pathology to understand or share what the patient feels or to interact with him.

These devices can be designed and materialized through a co-design and open design process that involves the patient, his family and healthcare specialists. The devices can be materialized collaborating with professionals who have design and technical skills (makers, hackers, engineers, etc.) and accessing digital fabrication technologies and enabling places such as makerspaces and Fab Labs. Finally, wearables are open source and codified projects, therefore customizable and (re) producible in a distributed way.

More precisely, it is observable the development of two distinct approaches in the product and user-driven/user-centered design of wear-to-care products: "operational" wearables are characterized by the "anonymity" of the design (to be a technical or technological object of recurrent use) and the guarantee of full effectiveness and control of the object. Therefore, they are not devices designed to show or emphasize functions related

to specific aspects of a disease (unless it is necessary, vital or functional to communicate them) but on the contrary they work to normalize the patient's life condition. On the contrary, "experiential" devices are designed to exaggerate emphasize all visual, tactile, olfactory, sound aspects that simulate physical, mental or behavioral states related to a specific disease. This is to make the experience "memorable".

The last phase concerns the adoption and scalability of projects at a social and entrepreneurial level. The "operational and functional" versions of the wearable can be materialized in a personalized way by patients with the support of patient associations and the verification of healthcare specialists. In this way, errors and risks are eliminated and patients are fully accepted. In parallel, these devices can be implemented at an entrepreneurial or industrial level by designers and manufacturers who have participated in the co-design phase. In this case, they would populate market niches that still lack dedicated solutions. On the other hand, thanks to the integrated support provided by companies, patient associations and other stakeholders, "experimental/experiential" wearables can be developed and disseminated on a larger scale by organizing awareness raising initiatives that aim to decontextualize the context of use of these solutions, stimulate or "normalize" the use of these devices, encourage fundraising for the production of "operational/functional" wearables.

Lessons learnt from the DermAware project, contextualized in a wider framework of innovations within the healthcare sector, highlights some key steps:

- design of wearables should go beyond the pure technical and functional dimension and must work on a more extensive, open, inclusive and participatory concept of "care";
- design of wearables with a dual nature – "operational and functional" and "experimental and experiential" - can provide useful elements and indications to improve the quality and effectiveness of the interactions between patients, formal and informal caregivers and the inclusion of patients in society;
- design of open and adaptable wearables for different utilities can be a real possibility for populating niches still lacking dedicated solutions.

Summarizing experiences and reflections we can propose a first general definition of "Wear-to-Care" as an area of potential innovation characterized by the development of open and collaborative design and materialization processes aims to produce interactive wearable devices that improve the effectiveness in the personal disease monitoring and increase the level of understanding and social awareness of the effects these pathologies have on patients' lives.

Starting from the experience gained through the prototyping of DermaTrack first and then DermAware, it emerges that we are still witnessing an experimental phase in the conception of new types of wearables. However, it is precisely the design openings that these experiments still present that can be considered as a testimony of how the concept and approach of Wear-to-Care can be further explored, until a stabilization is achieved. Further experimentation and collaborations with technological partners are currently underway to further ameliorate both DermaTrack and DermAware. The real challenge in this sense will be to transform an entire experiment into a certifiable and distributable product on the market.

References

1. Bianchini, M., Maffei, S., Bolzan, P.: Distributed design for Distributed Care. In Armstorng, K., Diez, T., Goldapple, L., Schmidt, A., Villum, C. (eds.) Design Remix Share Repeat. How distributed design is changing the way makers and designers approach collaboration, tools and the market. Institute for Advanced Architecture of Catalonia (2019)
2. DeMonaco, H., Oliveira, P., Torrance, A., Von Hippel, C., Von Hippel, E.: When Patients Become Innovators. MIT Sloan Management Review, Spring 2019 IssueResearch (2019). https://sloanreview.mit.edu/article/when-patients-become-innovators/. Accessed 31 Jan 2020
3. Maffei, S., Bianchini, M., Parini, B., Delli Zotti, E.: MakeToCare. An Ecosystem of user-centered actors and solutions for innovation in the healthcare sector. 1st edn. Libraccio Editore (2017)
4. Maffei, S., Bianchini, M., Parini, B., Cipriani, L.: MakeToCare2. Patient innovation in Italy between project and market. 1st edn. Libraccio Editore (2019)
5. Kanstrup, A.M., Bertelsen, P., Nøhr, C.: Patient innovation: an analysis of patients' designs of digital technology support for everyday living with diabetes. Health Inf. Manag. J. **44**(1), 12–20 (2015)
6. Krummel, T.M.: The Rise of Wearable Technology in Healthcare. JAMA Network Open Health Inf. **2**(2) (2019)
7. Oliveira, P., Zejnilovic, L., Canhão, H., Von Hippel, E.: Innovation by patients with rare diseases and chronic needs. Orphanet J. Rare Diseases **10**(1), 41 (2015). https://ojrd.biomedcentral.com/articles/10.1186/s13023-015-0257-2. Accessed 31 Jan 2020
8. Sienkiewicz, D., van Lingen, C., e Bedlington, N., Bullot, C., Immonen, K.: The added value of patient organizations. www.eu-patient.eu/globalassets/library/publications/epf_added_value_report_final.pdf. Accessed 10 Feb 2020
9. Senra, M.S., Wollenberg, A.: Psychodermatological aspects of atopic dermatitis. Br. J. Dermatol. **170**(1), 38–43 (2014)
10. Slattery, M.J., Essex, M.J., Paletz, E.M., Vanness, E.R., Infante, M., Rogers, G.M., Gern, J.E.: Depression, anxiety, and dermatologic quality of life in adolescents with atopic dermatitis. J. Allergy Clin. Immunol. **128**, 668 (2011)
11. Wollenberg, A., Barbarot, S., Bieber, T., Chriten-Zaech, S., et al.: Consensus-based European guidelines for treatment of atopic eczema (atopic dermatitis) in adults and children: part I. J. Eur. Acad. Dermatol. Venereol. **32**(5), 657–682 (2018)
12. Rønnstad, A.T.M., Halling-Overgaard, A.S., Hamann, C.R., Skov, L., Egeberg, A., Thyssen, J.P.: Association of atopic dermatitis with depression, anxiety, and suicidal ideation in children and adults: a systematic review and meta-analysis. J. Am. Acad. Dermatol. **79**(3), 448–456.e30 (2018)
13. Silverberg, J.I.: Atopic dermatitis in adults. Med. Clin. North Am. **104**(1), 157–176 (2020)
14. Zuberbier, T., Orlow, S.J., Paller, A.S., Taïeb, A., Allen, R., Hernanz-Hermosa, J.M., Ocampo-Candiani, J., Coxh, M., Langeraari, J., Simon, J.C.: Patient perspectives on the management of atopic dermatitis. J. Allergy Clin. Immunol. **118**(1), 226–232 (2006)
15. Morley, J., Floridi, L.: The limits of empowerment: how to reframe the role of mhealth tools in the healthcare ecosystem. Sci. Eng. Ethics **26**, 1159–1183 (2020)
16. Pardameana, H., Soeparnoa, B., Budiartoa, A., Baurley, J.: Comparing the accuracy of multiple commercial wearable devices. In: 4th International Conference on Computer Science and Computational Intelligence 2019 (ICCSCI) (2019)
17. Aroganam, G., Manivannan, N., Harrison, D.: Review on wearable technology sensors used in consumer sport applications. Sensors (Basel). **19**(9), 1983 (2019)
18. Banerjee, S., Hemphill, T., Longstreet, P.: Wearable devices and healthcare: data sharing and privacy. Inf. Soc. **34** (2018)