Applying the DATEMATS Method and Tools to Wearable ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies for Caring and Well-Being

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Applying the DATEMATS Method and Tools to Wearable ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies for Caring and Well-Being

Stefano Parisi

Abstract The chapter presents and discusses the theoretical background, original methodology, format, and results of the workshop "Interdisciplinary challenge on Emerging Materials and Technologies (EM&Ts)" with a focus on Interactive Connected and Smart (ICS) Materials for Wearable Technologies. ICS materials are defined as systems combining inactive materials, stimuli-responsive smart materials, and embedded sensing, computing, and actuating technologies. They can sense and communicate data from the body or the environment, and they can perform interactive behaviours. One of the application sectors where these are more exploited is wearable technologies. These materials can be embedded into clothing or worn on the body as electronic textiles (e-textiles), implants, or accessories. The challenge was used as a way to transfer new knowledge on innovative materials to design and engineering students and to establish a dialogue between students, researchers with extensive materials-focused expertise, and companies interested in EM&Ts. The workshop presented in this paper was held at Politecnico di Milano, Design School, from 12 to 16 July 2021. The methodology of the workshop follows a framework built by collecting, analysing, and systemically formalising innovative tools, methods, and approaches for designing and learning how to design with advanced materials. It identifies three phases: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project. This framework defined the original structure and agenda of the whole workshop. Therefore, the workshop was based on a combination of hands-on experimentation, design activities, and lectures by the teaching staff of the four universities and by partnering companies (design pills). Students applied this unique design methodology developed within the project to design with four Emerging Materials and Technologies (EM&Ts). The method and tools developed by the staff supported students in understanding, exploring, and shaping, and applying EM&Ts, and finding design

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opportunities from their integration. Indeed, the main EM&Ts explored in the workshop are Interactive Connected and Smart Materials (ICS Materials), but all the other EM&Ts researched in the project were integrated: Nanomaterials, Experimental Wood-based Materials, and Advanced Growing Materials. In this interdisciplinary challenge, a real-life design brief was given to students with the cooperation of two partner companies: Comftech and SCILIF. The joint challenge with the title "Designing with ICS Materials: a dialogue between e-textiles and active lighting technologies" was about using the two patented technologies produced by the companies—a textile sensor detecting biosignals, and SunFibre active lighting system—as a platform to develop interactive, connected, and smart tangible interfaces for new application sectors focused on emotions and stress management, from well-being to entertainment, to safety. Twenty-three students worked together in six multi-disciplinary teams to find solutions for this challenge and to produce product concepts, prototypes, and material samples. The results are described and discussed in the chapter and include interactive garments for healthcare, improving safety at work, sharing emotions in leisure activities, and for the well-being of elderly people and kids. The discussion of the results and the whole methodology is informed by the feedback provided by students through a questionnaire and by teaching staff observation.

1 Theoretical Background: ICS Materials and Their Implication in Design and Learning

ICS Materials is a recent and inclusive definition to describe complex and hybrid material-based systems with sensing, actuating, and interactive capabilities. With these capabilities they can sense and communicate data from the body or the environment, and they can perform interactive behaviours (Parisi et al. 2018; Rognoli and Parisi 2021a). To do this, they can combine inactive materials—for example, textiles, often used as a support—, stimuli-responsive smart materials—for instance, thermochromic pigments and shape memory alloys, and embedded sensing, computing, and actuating technologies—for example, touch sensors and LED technologies. Among different industries, from interactive furniture to smart architectures, one of the application sectors where these are more exploited is wearable technologies. Indeed, these materials can be embedded into clothing or worn on the body as electronic textiles (e-textiles), implants, or accessories. They have applications in health management, sportswear, industrial workwear, temperature control for well-being and safety, and entertainment, just to mention a few of them. In this sector, ICS material finds a design space overcoming most of the technological challenges implied by these technologies and bringing aesthetical and functional advantages. ICS materials enhance aesthetic enjoyment by triggering the effect of surprise and by creating multi-sensory experiences. Moreover, they have the transformative role of making invisible data tangible and information more accessible, enabling users to behave more awarely and proactively. Smart textiles and wearables may have a huge impact on the sport and healthcare industries: indeed, they can be used to monitor and support body activities. For example, they can be used for health prevention and rehabilitation. ICS materials allow wearables to constantly adapt to the users' needs for their well-being. Also, they can monitor environmental data and stimulate awareness and conscious behaviours, by creating functional and emotional relations between people and other entities (people, environments, and other artefacts).

As the definition of ICS Materials is an umbrella that encompasses components with different roles—such as sensors, actuators, connectors, processors, and so on—and of different natures—computational, mechanical, chemical, and even biological, the phenomenon has been observed before and investigated by scholars in Design, Material Science, and Human–Computer Interaction leading to concepts and definitions that approaches such materials from different angles.

Brownell (2014) elaborated the concept of expanded matter or x-matter, i.e., materials effectively enhanced with additional capacities, such as tracking, sensing, responding, and interacting, by the integration of information technologies. Similarly, Augmented Materials (Razzaque et al. 2013) refer to materials with generic physical and computational properties, in which electronics are seamless and embedded during the fabrication of the material. The definition of Computational Composites (Vallgårda 2009) identifies composite materials in which at least one of the components has computational capabilities. Smart Material Composites (Barati 2019) highlight how smart materials can work together in a system.

The application of these materials in design projects introduces new requirements in design and teaching methods and techniques. Indeed, such material contributes to unfolding a critical reflection and a call to action on shifting products towards a novel dimension characterized by hybridization, dynamism, and interactivity. To frame the workshop methodology, a State of the Art has been carried out (Parisi 2020) and is here shortly introduced, focusing on approaches, methods, and tools applied in design processes and learning environments.

In Design and Engineering schools and universities, teaching activities have already been carried out with a focus on the application of smart, interactive, and connected materials. Although these experiences are still relatively recent and experimental, it is possible to recognize precise design and teaching methods, approaches, and tools that have been applied to transfer knowledge, experiment, ideate, and develop a design with interactive, connected, and smart materials. Among these methodologies, some of them are focusing specifically on ICS Materials (Parisi and Rognoli 2021; Ferraro and Parisi 2020a, b), others broadly on materials with interactive, connective, and smart characteristics (e.g., smart materials, smart material composites, tangible interactive surfaces, e-textiles), while others address generically emerging material, including interactive and smart materials, but not limited to. I present a selection of design processes and teaching experiences identified from the literature review and based on our experience as educators, pointing out the most relevant observations on the approaches, methods, and tools applied.

Mixed sources for learning and understanding interactive and smart materials. One of the most applied approaches to gain knowledge about materials is the mixed approach (Haug 2019), combining multiple learning sources. Examples of these sources are direct experimentation with materials, reading texts, watching videos, and discussions with peers, instructors, and experts. Tangible materials samples are efficient tools to gain an understanding of novel materials and stimulate the creative process through direct manipulation (Haug 2019; Pedgley 2010; Rognoli 2010). In this respect, one of the problematic issues when dealing with advanced materials—including smart materials—is that physical samples might not be easily accessible. Therefore, it is fundamental to provide designers and students with the opportunity to understand interactive and smart materials in the absence of physical samples. Examples in education show tutors replacing samples with other alternative learning materials in the format of databases (Hölter et al. 2019) and in the format of canvases or cards (Colombo 2016). Considering the novelty of interactive and smart materials, other principal sources for gaining and sharing information and inspirations are open-access platforms presenting case studies, instructions, and tutorials, like Materiability (http://materiability.com) by Manuel Kretzer and Openmaterials (http://openmaterials.org) by Catarina Mota. Kretzer (2017) argues that it is a priority that designers acquire active material literacy before applying them, including learning, using, and qualifying their potential. The suggested learning approach is through multi-disciplinarity, hands-on explorations, digital fabrication, access to open-source information and technologies, and the development of speculative and critical applications. Similar approaches are shared within the FabricAdemy programme (https://textile-academy.org), coordinated by Anastasia Pistofidou (FabTextiles/Iaac FabLab BCN) and Cecilia Raspanti (TextileLab Amsterdam/Waag Technology & Society).

The role of application and contextualization. The methods presented in these pages are fundamentally embedding Active learning (Bonwell and Eison 1991). In material education for design, students are often engaged within a design challenge or a project brief, as it conventionally happens in practice. This denotes a tendency towards application-oriented design processes in education and training programmes for designers. These methods are based on applying the materials into a product, challenging their limits and potentials, and promoting new product development and innovation. Often, they involve stakeholders, for example, companies, to contextualize the materials and reinforce the connection between Academia and Industry (Piselli et al. 2018). Another common approach is context-driven. Whether it is an industrial sector, a situation, or a broader social scenario, the context is defined as a starting point of the design process and provides borders to the limitless possibilities of interactive and smart materials. In a context, interactive and smart materials and their resulting application will be situated in a discourse with industry and society involving not only technological limitations and opportunities but also social necessities. Indeed, one challenge related to interactive and smart materials arises from the significant risk of developing a product embedding an emerging material or technology without creating real value for society. On these lines, the Design-driven Material Innovation Methodology (DdMIM) (Lecce and Ferrara 2016) is a systematic approach for design students and practitioners, research centres, and small-medium enterprises, based on the understanding of the broader socio-cultural scenario before selecting advanced materials, including smart ones. It allows the development of one or more materials starting from scientific discoveries, material patents, or production processes, identifying scenarios of application, and developing new products DdMIM has been used in the application of smart materials and interactive technologies for tangible interfaces in products and interiors in design workshops at the School of Design of the Politecnico di Milano (Ferrara and Russo 2019).

Speculative and critical design approach. Some other methods are based on a speculative design approach using critical thinking and prototyping to question technological, societal, and ethical implications of advanced materials and technologies in future scenarios. This approach overcomes their evident current technological limitations and scarce availability by envisioning and projecting future development and application of interactive and smart materials. In this respect, Barati et al. (2015) argue that a "designer's naïve perspective with respect to every technical detail of a technology allows them to see new applications". One example of a speculative design method in the context of smart materials is the Dystopian Thinking. It uses science fiction-based scenarios as a starting point to generate ideas for smart materials and wearable applications in future or alternative situations. The design process was supported by a toolkit based on inspirational cards and canvases. With a more hands-on approach, the InDATA project team at the Design Department of the Politecnico di Milano (http://www.indata.polimi.it) carried out an experimental design activity in the format of the Hackathon "Data < > Materials". The design process was focused on developing interactive devices and wearables by combining speculative design, do-it-yourself bioplastic making, electronics programming, embedding, and digital fabrication with the support of the Fab Lab environment (Parisi et al. 2021). The design process used future scenarios involving the use of technologies as a starting point and was facilitated with mixed learning and design tools with the aim of understanding materials and technologies and carrying out material experimentation, concept ideation, and prototyping.

On these lines, another design approach is the one applied by young designers and students at the Institute for Material Design IMD at the Offenbach University of Arts and Design (http://imd-materialdesign.com). There, they are dealing with active material systems, augmented with digital, adaptive, or interactive components. The design process is based on hands-on exploration and prototyping of materials demonstrators, working in a hybrid design space where form, material, and technology overlap. The results of this hybrid practice are prototypes encouraging the discussion about material authenticity and speculative applications (Parisi et al. 2020).

In the workshop Coded Bodies (https://codedbodies.com/), interaction designer Giulia Tomasello engages companies, design practitioners, and students in a design process combining traditional textile techniques, sensing and actuating technologies, smart materials, and biological textiles to develop a speculative concept and prototype physical soft wearables, adaptive structures, and active second skins.

Multi-disciplinary approaches. The urgency for creating a multi-disciplinary environment to learn, experiment, and develop applications of interactive and smart materials is expressed in a large number of cases. Indeed, the interactive and smart materials area is mainly situated in the intersection between design, materials, and interaction, practically involving electronic circuits design and material crafting, along with design capabilities. Since only a few cases reported to actually operate in this multi-disciplinary field with co-tutoring or cross-field collaborations (Schmid et al. 2013), this is still a significant gap. Cross-disciplinary knowledge includes sustainability. The design process used at the Interactive Organisms Lab coordinated by Katia Vega focuses on exploring sustainable interactive objects and wearables starting from hands-on exploration with organic and growing materials (mycelium) combined with interactive technologies (Lazaro Vasquez and Vega 2019).

Experiential learning through a material-centred approach. An approach that is fundamentally embedded in design practice and education is Experiential learning (Kolb 1984). This approach allows designers to gain procedural knowledge about novel materials by learning through making (Pedgley 2010). Most of the mentioned methods emphasize direct experimentation through exercises and hands-on exploration. Material tinkering is a goal-free and playful exploration with physical components—both materials and technologies—for understanding their potentials and guiding further developments (Alarcón et al. 2020; Asbjørn Sörensen 2018; Parisi et al. 2017; Rognoli and Parisi 2021b; Santulli and Rognoli 2020). Schön and Bennett (1996) described how the design process could be approached as a conversation with materials, through which the practitioner gets to know the materials.

On these lines, the Enactive Environments Lab (http://www.enactiveenvironments.com/) founded by Karmen Franinović reflects on the direct exploration of responsive and active materials (Franinović and Franzke 2019) in creative research processes as a negotiation with materials—with their form, behaviours, and interaction as one—rather than imposing ideas and forms on them. Both creative hands-on explorations using analogic and digital materials, tools, and methods, and the experience of the user enhance embodied and situated knowledge engaged in both tacit and creative processes and physical interaction.

Therefore, it becomes necessary to create methods based on the central role of materials in the design process. Often one material or a selection of materials is the starting point of the design process. This is the case for the Material-Driven Design (MDD) method developed by Karana et al. (2015). Practicing this method, practitioners and students start from a material at hand and design for material experience, by tuning their physical qualities, sensory profile, and emotional and meanings associations. This method targets novel materials with yet limited applications and unrecognizable identity—including interactive and smart materials—to foster meaningful materials experiences and ultimately materials acceptance by the society and the market. The method was applied to designing with and for intelligent composite materials, precisely an underdeveloped piezoelectric and light-emitting smart composite material (Barati 2019).

Simulation techniques. One of the problematic issues of designing and teaching for interactive and smart materials is often the scarce access not only to material samples, but also to equipment, facilities, and multi-disciplinary environments to experiment and produce prototypes. Instead, simulation can be used to exemplify or mimic the sensory qualities or the physical behaviours of the intended material by creating, collecting, and combining other material samples (Karana et al. 2015).

Metaphors and analogies can be used to inspire and communicate the performance and behaviours of smart and interactive materials. Experience prototyping and body storming techniques can be used to physically explore, test, and define the functionality and performances of ICS materials in the early stages of the design process or in the absence of physical materials or equipment (Piselli et al. 2015). Even in hands-on experiences, metaphors can be used to inspire forms and behaviours in the ideation phase. This is the case of the design process applied by Schmid et al. (2013) focused on developing glass-based tangible user interfaces, starting from the suggestions provided by the glass itself, which is then implemented with electronics. Simulation techniques can replace physical samples and inspiring forms and interactions.

User-centred approaches. The user interaction and expectations in relation to the material aesthetics and performances are essential, both considering physical body involvement and emotional engagement. In the design process described by Russo and Ferrara (2017), the role of the whole-body experience and somaesthetic was vital in ideating with interactive materials. In another case (Colombo 2016), the role of user experience in dealing with smart material-based interactive products is emphasized in the use of tools for enhancing product sensory experience. Like the afore-described MDD method, these processes are fundamentally user-centred, considering the user involved since the initial stages, often through user studies.

Findings from the review identify the current State of the Art on methods, approaches, and tools to use by design and engineering practice and education when involving interactive, connected, and smart materials. These informed the setup of an original workshop for ICS Materials in the wearable sector, in the scope of the project DATEMATS. The objectives and structure of the workshop are presented in the following section.

2 The Workshop "Designing with ICS Materials: A Dialogue Between E-textiles and Active Lighting Technologies"—Objectives and Structure

The workshop presented in this paper was held at Politecnico di Milano, Design School, from 12 to 16 July 2021. The methodology of the workshop follows a learning and design framework developed in the scope of the project DATEMATS, working as a foundational methodological model to adapt and translate into the different activities of the projects (Parisi and Ferraro 2020; Ferraro and Parisi 2020a, b). The DATEMATS methodology (Fig. 1) has been adapted in the four international workshops for students and in several events addressed to companies. The methodology was built by collecting, analysing, and systemically formalising innovative tools, methods, and approaches for designing and learning how to design with advanced materials. It identifies three phases here concisely described: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate

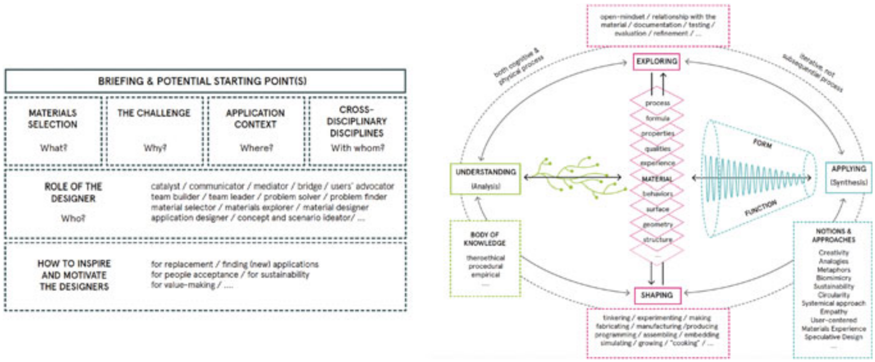
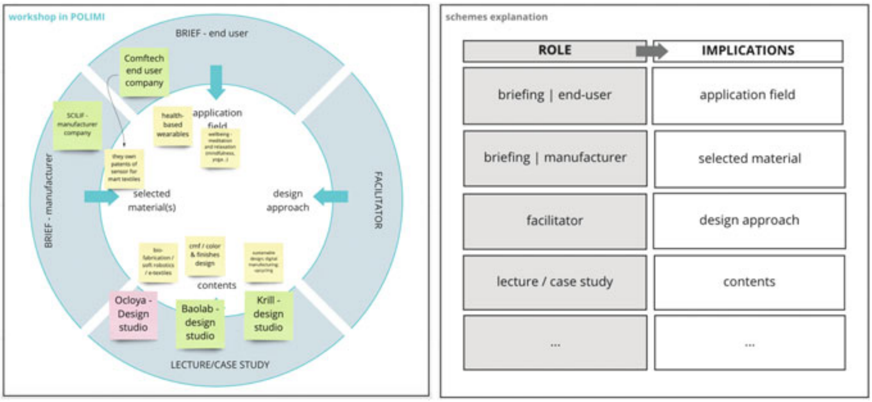


Fig. 1 The DATEMATS methodological framework

ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project (see Fig. 1).

This framework defined the original structure and agenda of the whole workshop. Therefore, the workshop was based on a combination of hands-on experimentation, design activities, and lectures by the teaching staff of the four universities and by partnering companies (design pills) (see Figs. 2 and 3). Students applied this unique design methodology developed within the project to design with four Emerging Materials and technologies (EM&Ts). The method and tools developed by the staff supported students in understanding, exploring shaping, and applying EM&Ts, and finding design opportunities from their integration. Indeed, the main EM&Ts explored in the workshop are Interactive Connected and Smart Materials (ICS Materials), but all the other EM&Ts researched in the project were integrated: Nanomaterials, Experimental Wood-based Materials, and Advanced Growing Materials.

The challenge. In this interdisciplinary challenge, a real-life design brief was given to students with the cooperation of two partner companies: Comftech and SCILIF. Methodologically, the contribution that the involvement of the companies brought to the workshop was both related to the selected materials and technologies to use as a starting point and the scenario of applications. Comftech is an Italian company that creates and sells wearable monitoring systems made from cloth. Comftech smart garments enable accurate measurement of a range of physiological parameters and offer reliable, continuous, and non-invasive monitoring (see Fig. 4). SCILIF is a Czech company that applies new technologies to make life safer ("Science for Life"). Their SunFibre Wearable Active Lighting Technology is a unique optic fibre lighting system encased in a textile coating. It increases visibility in darkness or low-light conditions. Comftech's textile sensor and Scilif's SunFibre are a technological pairing full of potential, as together they form a complete smart material system: the former is a sensor, the latter an actuator (see Fig. 5). The joint challenge with the title "Designing with ICS Materials: a dialogue between e-textiles and active



Figs. 2 and 3 A schematic representation of the actors involved in the workshop at Politecnico di Milano, with an explanation of their implications and contributions in the workshop. A schematic explanation of the roles and implications of the actors involved in the workshop at Politecnico di Milano

lighting technologies" was about using the two patented technologies produced by the companies—a textile sensor detecting biosignals, and SunFibre active lighting system—as a platform to develop interactive, connected, and smart tangible interfaces for new application sectors focused on emotions and stress management, from well-being to entertainment, to safety. The concept of well-being and stress management had a big emphasis in the framing of the briefing for the challenge, considering the current relevance and urgency that the topic represents in many fields, including design. It is widely acknowledged that mental health and well-being have increasingly become prominent issues to tackle, especially in recent years, considering the aftermath of the recent COVID-19 pandemic. Keeping a regular fitness routine, good sleeping habits, and contemplative and meditative activities are recognized as beneficial for improving users' relaxation, stress relief, and ultimately mental well-being. Wearable artefacts based on smart textiles have the potential to support users in improving well-being and awareness in users' regular and special daily activities—including those based on sport and fitness routines, social and work activities, self-care, good sleeping habits, contemplation, and meditation. In this comprehensive scenario, textile sensors can detect and monitor physiological signals—such as heartbeat and breathing. Simultaneously, lighting technology can perform actuation to communicate information and stimulate body conditions with the use of rhythm, intensity, and colours. The technological platform constituted by these two components can even be combined with other elements making the wearable able to perform complex interactions, adapt to users' needs or preferences, or stimulate body conditions such as by changing shapes or temperature.

Design-pills. Three design studios working on materials-related topics were invited to take part in the workshop as lecturers. They presented their design

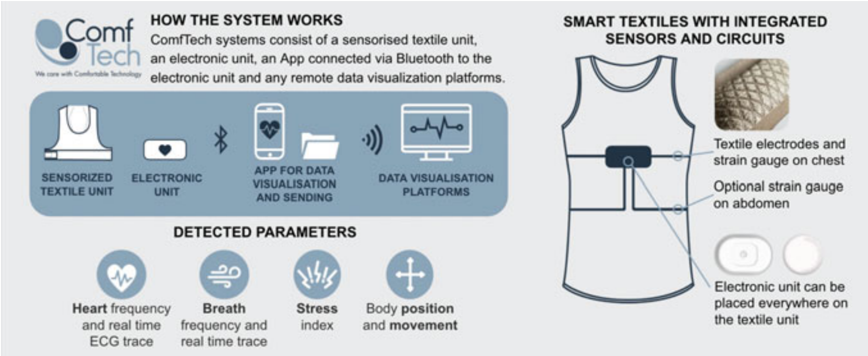


Fig. 4 A summarized description of ComfTech textile sensors technology

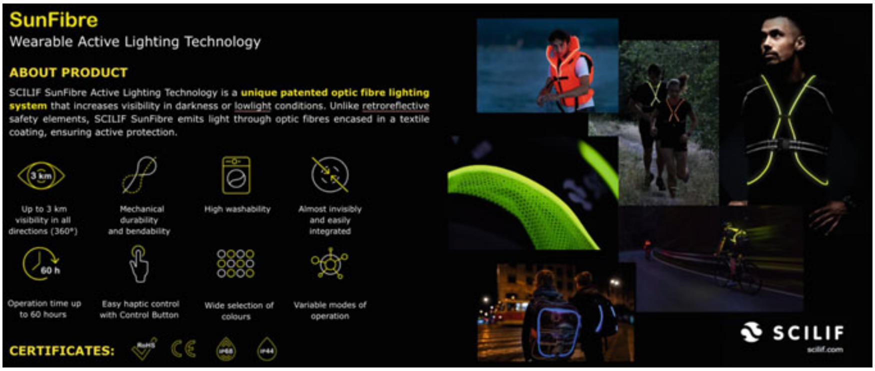


Fig. 5 A summarized description of Scilif's SunFibre active lighting technology

approaches and case studies from their professional practice with short presentations—the so-called "design pills"—and engaged students in an active discussion around design methods and tools in practice, often with the support of prototypes and samples. Krill Design is an Italian start-up born in 2028 proposing a Green Economic model of business that combines the need to recycle waste and create new materials by leveraging Circular Economic, Technological Innovation, and Creativity. They support people and organizations embracing sustainability through circular design. They enhance food waste through a process based on circular economic concepts, which makes it possible to transform organic scraps to generate Circular Materials and Circular Design. Boosting the re-valorisation of organic waste, Krill Design proposes converting it into innovative materials in pellet and filament format to 3D print products that collaborate to the reduction of pollution, promoting the transition from a linear to a circular economy system. Their pills were titled "From Trash to Treasure – circular design with reclaimed organic materials" (see Fig. 6). Baolab

Figs. 6 and 7 Image from the Design Pills by Krill Design. Image from the Design Pills by Baolab

is an Italian design studio that works in the field of Industrial Design with expertise in the fields of design strategy, research on materials and exclusively advanced technologic processes, colour & trend forecasting, and cmf design (colour, material, and finishing). Baolab professionals work at enhancing the sensorial qualities of a product, in consideration that consumers are most likely to link to their personal use. Their pill was titled "Material-Driven Design with a CMF approach" (see Fig. 7).

Ocloya Studio is the professional design practice by Loana Flores. It establishes a link between traditional textiles and new technologies, and she focuses on pedagogy and sustainability. She presented the pill "Experimentations with e-textiles and bio-textiles".

Teaching staff. Teaching staff from the four Higher Education Institutions (HEI) engaged in the DATEMATS project were involved, bringing their unique knowledge and expertise on each EM&T area and design-related topic, from creativity techniques to sustainability. The teaching staff supported students in every phase of the workshop, with presentations, discussion moments, and tutored group activities. The technical staff from the Prototyping Lab of the Politecnico di Milano was also involved in in-lab hands-on activities. A total of 7 tutors were involved in the workshop.

Tools. In the different phases of the workshop, the tools developed in the scope of the project's DATEMATS to support the methodology were used (see Fig. 8), in particular:

- The EM&Ts toolkit. A collection of 5 boxes for each EM&T including exemplar cases of materials of each area with tangible samples and textual and graphical

Fig. 8 Images of students using the tools during workshop activities

descriptions on properties and qualities of the materials—including environmental and smart attributes—, their manufacturing process, and their application potentials. They were mainly used in the first phase of the workshop to understand EM&Ts.

- The EM&Ts integration cards. A deck of cards showing the potentials and limits of combining two or more EM&T areas, by means of case studies, lists of advantages and disadvantages, and references to the scientific literature. They were used throughout the workshop to inspire students.
- Communication materials. A poster and presentation template were used to communicate in a homogenous and intuitive way the results of the workshop.

Activities. The workshop structure was built around the three phases of the DATEMATS methodology, namely: (1) Understanding the EM&Ts—where the fundamental knowledge is provided; (2) Exploring and Shaping the EM&Ts—where hands-on experimentation and tinkering is a way to stimulate ideas and understand the opportunities and limits of the materials and processes; (3) Applying the EM&Ts—the synthesis of the process when the material is embedded and embodied into a project. In this section, the main learning and design activities are described in chronological order, day by day.

Preparation. One week before the beginning of the workshop, an online meeting with all the participants was organized by the hosting teaching staff. The workshop's structure and objectives were introduced, and an interactive group-making activity was performed. In this activity, students were asked to introduce their background, skills, and expertise, in order to create multi-disciplinary teams. Participants were asked to get prepared before the beginning of the workshop with suggested reading and videos produced in the scope of the DATEMATS project.

DAY 1. The focus of the day was to understand the EM&ts by means of theoretical lectures, discussions with experts, and samples exploration. The day started by welcoming the participants, introducing the agenda overview, and introducing the objectives and activities of the workshop. The brief of the challenge was presented by Polimi with the support of an informative and inspirational presentation on wearable technologies. Presentations by the two companies followed, namely "Wearable systems for remote monitoring" by Comftech, and "Wearable Active Lighting…a new market segment" by SCILIF, and a discussion moment with "questions and answers" with the companies followed, with the support of a hands-on exploration of the companies' technologies (see Fig. 9). After this initial phase, students were introduced to the 4 EM&Ts, namely ICS Materials, Nanomaterial, Experimental Wood-based materials, and Advanced Growing materials, with presentations by the materials experts involved in the project, and a tutored group activity based on the exploration of the EM&Ts Toolkits and inspirational cards for EM&Ts integration. Day 1 ended with the first design pill by Baolab: "Material-driven design with a CMF approach".

DAY 2. The objective of the first half of the day was to discover the EM&Ts by experimenting with them and shaping them into simple explorative artefacts. The day started with an introduction to the tutored group activity: "Discover the materials and technologies through Exploring & Shaping, and block coding and circuits making" by Polimi Prototypes Lab Staff. An in-Lab hands-on experimental tutored groups activity followed and took place in the Polimi prototypes Lab. Different exercises involving the use of sensors, actuators, and micro-processors were proposed to students, aiming at the ideation of simple wearable objects. The activity aimed to support the exploration and understanding of the EM&Ts and stimulated the imagination and inspiration of design opportunities related to the brief. Tinkering was

Fig. 9 Highlight on activities performed during Day 1: presentations from the companies and samples exploration

used to inspire idea generation within the design process (see Fig. 10). The activity ended with a presentation of the results, discussion, and feedback. The activity was followed by a design pill by Ocloya, with the title "Experimentations with e-textiles and bio-textiles". The second half of the day was focused on a tutored group activity aiming at discovering the context and searching for opportunities based on the market and competitor analysis, the potential users and target, the research of design case studies, and desk research tasks. The expected outcome was research about the context through maps, visualization, benchmark, personas, and other tools.

DAY 3. The objective of the day was to define the concept idea. An extensive tutored group activity based on idea development and definition was carried out throughout the day, first focusing on brainstorming and mind-mapping activities, funneling in the development and definition of 2–3 ideas for each group (see Fig. 11). The ideas were presented to the companies and teaching staff in an intermediate presentation (see Fig. 12). Feedback from the companies helped to select one most promising design idea to develop further in the following phases. A design pill by Krill Design was presented, with the title "From waste, value for the future. Circular Design with reclaimed organic materials".

DAY 4. The objective of the activities on this day was to develop the project through the application of the EM&Ts. An extensive tutored group activity took place, based on project development and prototyping. The expected outcomes of the activity were concept development and prototyping and production of samples.

DAY 5. The last day was focused on finalizing the prototypes and presentations, ending with the final project presentation to the companies and teaching staff, followed by feedback (see Fig. 13). The outcomes of the application of the method

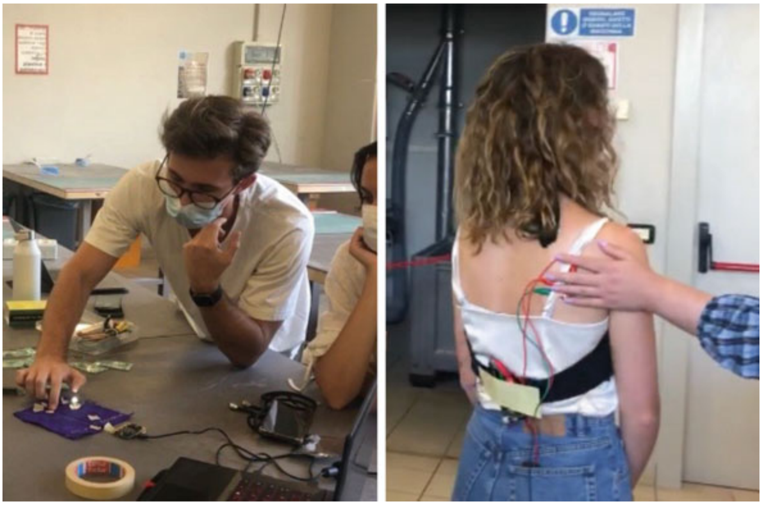


Fig. 10 Highlight on activities performed during Day 2: material tinkering, and in-lab hands-on activity with interactive technologies

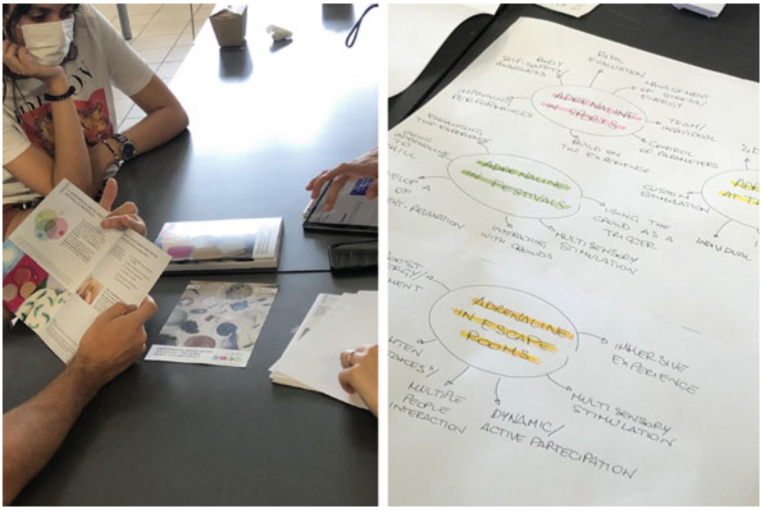


Fig. 11 Highlight on activities performed during Day 3: concept development and definition with the use of inspirational cards for EM&Ts intersection and creative techniques

Figs. 12 and 13 Students received continuous feedback to iterate their design concepts, through an intermediate design projects presentation on the Day 3. Students received continuous collection of feedback from the companies and the teaching staff to refine their projects, and final design projects presentations in the challenges are delivered, including the final presentation, a poster, and an (optional) physical prototype of the solution.

3 The Results: Six Smart Wearable Artefacts for Safety, Care, and Well-Being

The six concepts resulting from the workshop are described and discussed in this section. They include interactive garments for healthcare and caring, improving safety at work, sharing emotions in leisure activities, and for the well-being of elderly people and kids. For a deeper understanding, see the appendix with all the projects.

3.1 LIGHTCARE: A Smart Garment for Elderly Care

Project by Luca Cappetti, Davide Franci, Laura Pizarro, Sara Saccoccio.

LightCare (see Fig. 14) is a smart garment that monitors stress levels thanks to Comftech's smart textiles. Using SunFibre's lighting technology, it displays the mood of the person wearing it, calling others to action. It is a product system consisting of two wearable garments: one, integrated with sensors to be placed in direct contact with the skin and is able to monitor the person's stress level and health status; the others are worn over the clothes and, thanks to SunFibres, display the person's mood translated into colours. Depending on the stress level of the user and the situation in which they are, the colours of the light will vary to express different needs, based on colour psychology norms, e.g., red for anger and stress, orange/yellow for attention, green for safety, and blue for calmness. It is designed to be used by older people struggling to express themselves. It aims to stimulate empathy through colour and encourage interaction with others.

Moreover, the system includes as an extension a SunFibre frame in the form of a decorative piece of furniture that can be placed in the caregiver's house to inform them of the elderly person's status and whether they need intervention in a non-intrusive way. Clothing and decorative furniture are therefore two different devices to help and treat the stress of the user. In this concept, Comftech's textile sensor and Scilif's SunFibre are a technological pairing full of potential, as together they form a complete smart material system: the former is a sensor, the latter is an actuator. This wearable smart garment uses conductive threads to weave the circuit on the fabric itself and actuators, such as touch buttons and textile push buttons. It is therefore a coherent system that is fully developed in the fabric and thus offers otherwise unparalleled flexibility and comfort. In addition, the Nano-Tex nanomaterial fabric used as a substrate for the concept offers particularly suitable performance in conjunction with previous technologies. It is waterproof and non-conductive, elastic, close-fitting, and particularly durable. It was also chosen for its resistance to washing, dirt-repellent,

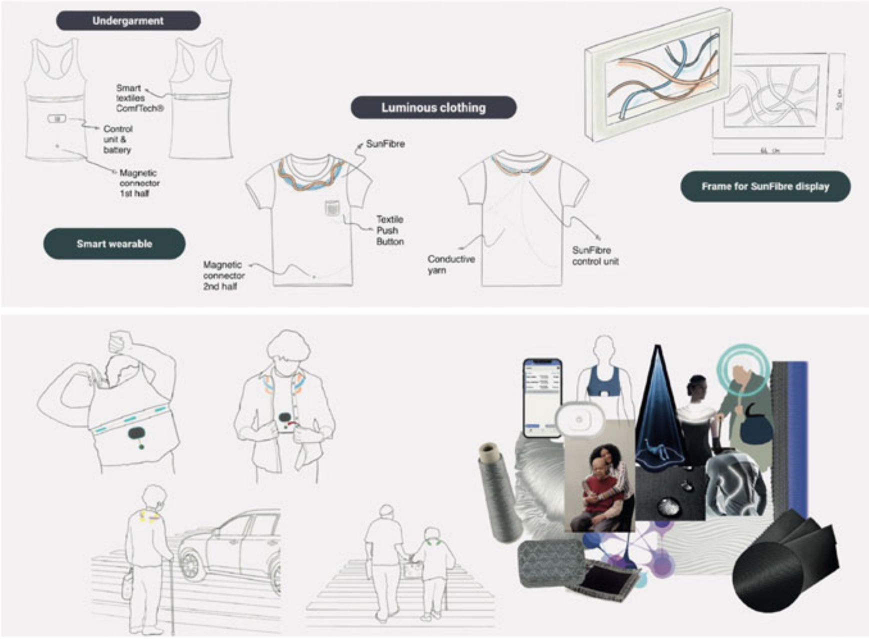


Fig. 14 Visualizations of LIGHTCARE: a smart garment for elderly care. Project by Luca Cappetti, Davide Franci, Laura Pizarro, Sara Saccoccio

and breathability, which are desirable characteristics for wearing on the skin. In conclusion, sometimes dependent people, both physically and mentally, need help but as they don't like to ask for it or feel like a burden they don't do it. This concept aims to save them from having to ask for help; people will do it automatically when they see the need reflected in the luminous device. In addition, the decorative device will help these people to understand their emotions and needs and we will keep their loved ones informed in a discreet and aesthetic way. Future steps for the concept are exploring a better integration with heavier clothes, integration in all types of clothes using a removable light system, and a more effective direct therapy on elderly people by means of this concept.

3.2 U-EMOTIONS: An Emotional Exploration Aid for Children

Project by Leonardo Cariga, Roxana Tavoosi, Elisa Igoa.

The core idea of this project is to propose a wearable and non-invasive tool to help children to communicate, express, and understand their feelings better during their development. It also facilitates parents in understanding the emotional growth of their kids. U-Emotions (see Fig. 15) is a well-being system for children to help them understand how they feel, using the technologies of the companies as a sensing and communication tool. Comftech's textile sensors are indeed a powerful tool for understanding and communicating with our bodies. Instead, Scilif's SunFibre can be used to communicate with others and provide feedback in a very intuitive and quick way. The technology is contained in a Ioncell-F (95%) and Ecolastane (5%) t-shirt.

Through this wearable garment, the sensors can collect data. The actuators can make them visible through the light activation, showing different patterns and colours according to the kid's emotions. Ecolastane gives flexibility to the garment. Ioncell-F is based on fibres coming from cellulose pulp. This material presents very good characteristics related to transpiration and soft contact with the skin, which is an important requirement in products for children. Further steps for the development of the concepts concern the inclusion of a tactile-sensitive conductive textile to improve the product or integrating sound effects that respond to the stimulus of the child. Another possibility could be integrating AI mechanisms in order to be more effective in understanding the behaviour of the child and helping to be more effective in identifying different emotions.

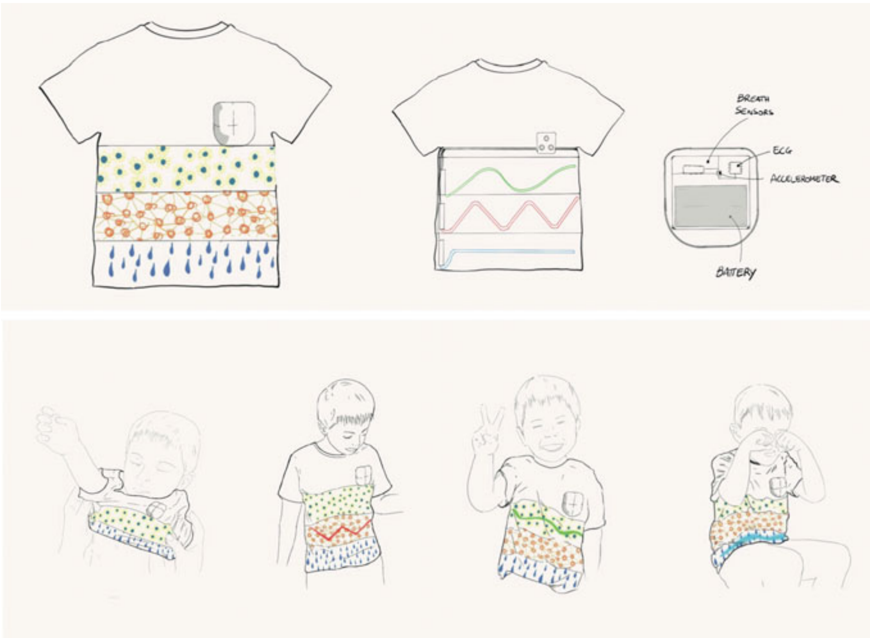


Fig. 15 Visualizations of U-EMOTIONS: an emotional exploration aid for children. Project by Leonardo Cariga, Roxana Tavoosi, Elisa Igoa

3.3 SENSE-E WORKPANTS: Tech-Wear for Repetitive Strain Injuries Prevention

By Alice Ballestra, Ludovica Bonaldo, Francesco Carlucci, Hanna Selim.

The concept (see Fig. 16) is focused on integrating Scilif's SunFibres and ComfTech's sensors into the fabric of couriers' clothes to detect movement that may trigger RSI (Repetitive Strain Injury) and improve their visibility during shifts. Repetitive Strain Injury is a broad term to describe the pain felt in muscles, nerves, and tendons caused by repetitive movement and overuse. Sense-e Workpants can help prevent RSI through early detection of strains and anticipate needed therapy or rehabilitation by integrating strain gauge textile sensors in vulnerable areas of the body to measure the movement. During the operation time of the device, it collects and stores data and then shares it to the company. Then, they would be able to elaborate the data through AI systems and optimize the work hours of their staff and give feedback to the workers. For what concerns smart textiles, this concept exploits the stretch qualities of the conductive silicone circuits, which allow having an adherent connection between the underpants and the skin of the user, without obstructing the movement while working. Alternatively, to the entire underpants, it is also possible to have more accurate local bends for knees, shoulders, and wrists. Connected to this smart textile, there is a central unit, contained in a plastic shell, for which Sulapac biopolymer is used, thanks to its optimal characteristics of resistance and insulation. The connection between the unit and the smart underpants can be by metal buttons or just by the contact between two surfaces made by superconductive Carbon NanoFibers (CNF). In fact, for their structure and orientation, they guarantee a perfect and strong joint between the parts together with excellent electrically conductive properties.

3.4 CAREN: A Wearable Monitoring System for Hospitals

Project by Andrea De Bernardi, Mikel Lasa, Shonglin aka Raveesha Rajendra Gaekwad, Shuai Liu.

Caren (see Fig. 17) is a wearable technology that aims to enhance a patient's medical care response in wards and hospitals where individual bed monitors are not available for every patient. Caren is ideally designed for basic wards in hospitals where it is often not possible to give attention to each patient all the time. This design solution proposes to aid the nurses and doctors in identifying a patient in need of urgent help. It uses SunFibre's optical fibre to visually alert the medical staff nearby, whether it is while the patient is sleeping or walking in the halls of the hospital. The SunFibre is triggered by Comftech's sensor that senses any kind of distress from the patient's body. In case of severe situations, where immediate treatment is needed, the technology can be easily removed, and the garment can be opened at once because of the snap buttons in the centre front. This project uses a combination of Nanomaterials and ICS materials. These textiles have numerous potential applications, such as the

Fig. 16 Visualizations and prototype of SENSE-E WORKPANTS: tech-wear for repetitive strain injuries prevention. By Alice Ballestra, Ludovica Bonaldo, Francesco Carlucci, Hanna Selim

ability to communicate between devices, conduct energy, and improve physical and mechanical performance. It can be used as a non-invasive monitoring wearable for healthcare, as optical fibres may be easily integrated into a textile. Future development of the concept regards improving the sustainability and comfort of the garment.

3.5 JACKTIVE: A Sportive Jacket to Alert for Panic Attacks

Project by Diego Piracoca, Sara Kashfi, Sonia González, and Bianca Muresan.

Jacktive (see Fig. 18) is a jacket for hiking that helps people to calm down during a panic attack, through sensory and visual stimuli integrated into the garment. Thanks to Scilif's SunFibre it allows to improve people tracking when rescue actions are needed. More than being a simple garment, this sportive and smart jacket aid people during a panic attack, helping them to calm down using a diaphragmatic movement around their chest to stimulate and guide the breathing rate single-handedly, by means of controllable inflatable parches. This response is activated when Comftech's textile sensors located in the wrists identify an abrupt change in the breathing and heart rate. At the same time, the system turns the optic fibre lightings on to make the identification and tracking of people easier in environments with tough visibility in

Fig. 17 Visualizations and renders of CAREN: a wearable monitoring system for hospitals. Project by Andrea De Bernardi, Mikel Lasa, Shonglin aka Raveesha Rajendra Gaekwad, Shuai Liu

the forest or at night in case of disorientation during hiking. The concept makes use of ICS Materials in combination with nanomaterials and growing materials. The textile of the jacket is formed by three layers of materials, one of them is the Aquapel, graphene printed on a textile to transmit the electrical signals, and polyester to protect the user from any wet substance. The project proposes to use wearable smart materials and exploit their functional advantages in sensing several biological variables of the human body to trigger a response during panic attacks. Polyhydroxyalkanoate (PHA), a polymeric growing material, gives the project a sustainable input to decrease the environmental impacts during its product life cycle. In terms of feasibility, the project is still in a conceptual phase because the application of the graphene to connect two electrical components and the inflatable patch is still in the phase of testing its reliability. Further development of the concept regards product testing, feasibility, integrating sound to control the panic attack, and exploring the possibility of partnering up with hiking guides and integrating a GPS system.

Fig. 18 Visualizations and prototype of JACKTIVE: a sportive jacket to alert for panic attacks. Project by Diego Piracoca, Sara Kashfi, Sonia González and Bianca Muresan

3.6 ADRENALIGHT: A Smart Garment for Shared Adrenaline Experiences

By Adriana González, Giuseppe Fazio, Martina Paramatti, Andrea Ettorina Tremari.

Adrenalight (see Fig. 19) is a wearable system that allows you to show and share your instant excitement in extreme, adrenaline group experiences, through multi-sensorial stimulation. The concept is thought to be used in any kind of adrenalinic group activity to function at its best. The main purpose of this is because the product detects some body parameters (such as heart rate and breathing activity) that analyse the adrenaline experience and replicate all these feelings into visual feedback. The goal is to involve all the people into an adrenaline situation and to use one person as a trigger for the others to regulate the level of adrenaline if it's too low for others. The main idea is to enhance the adrenaline of the users by monitoring their constants with Comftech sensors and provide a visual answer with Scilif lights. These sensors are fully integrated into the textile band, this provides the user a comfortable and washable option, which does not disturb the user. Also, the feedback provided by the light is related to the user's constants and the people around wearing these wearables. The external part of the wearable will also be made with a sustainable textile made of 100% bio nylon. This innovative thread with a renewable energy origin makes this fabric a profitable solution. Although the technology used is completely developed

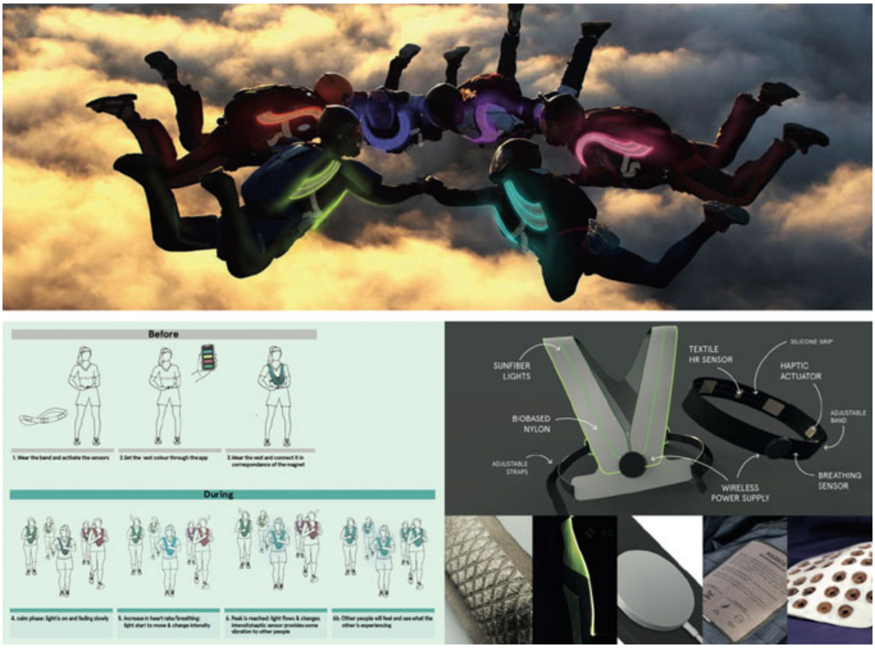


Fig. 19 Visualizations of ADRENALIGHT: a Smart garment for shared adrenaline experiences. By Adriana González, Giuseppe Fazio, Martina Paramatti, Andrea Ettorina Tremari

individually by these companies, the integration of them offers a new solution for the market. Future opportunities for this wearable could be developed by including technologies such as biomaterials.

4 Discussion and Conclusion

The discussion of the results and the whole methodology is informed by the feedback provided by students through a questionnaire to evaluate different aspects of the workshop and by teaching staff observation. Data were collected by the triangulation of observations of the activities (rapid ethnography) with direct questions to participants to provide contextual feedback, analysis of responses to questionnaires, and analysis of the results of the workshop (i.e., design solutions), including the analysis of workshops materials (e.g., posters and presentations).

The questionnaire was based on quantitative data, by rating on a Likert scale of 1–5, and qualitative data, by open questions. Eighteen over twenty-three students replied, corresponding to 80% of the participants. The questionnaire was divided into different sections to assess and elaborate on different aspects of the workshop,

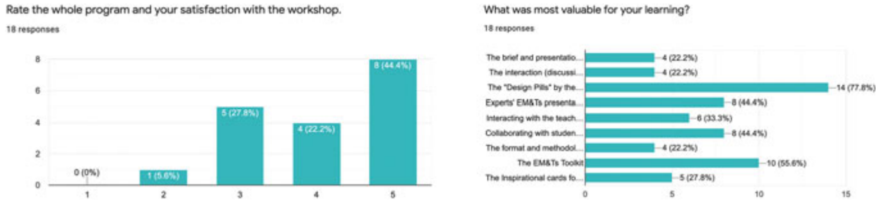


Fig. 20 Workshop feedback, charts 1 and 2

from the overall organization to the applied tools and methodology (see Figs. 20, 21, 22, 23, and 24).

The overall satisfaction is high (chart 1, average = 4.01 on a scale from 0 to 5) and the objectives of the workshop are fulfilled in terms of acquired knowledge (chart 3, average = 4.22 on a scale from 0 to 5) and of transferred methodology and tools (chart 4, average = 3.84 on a scale from 0 to 5). Students addressed that

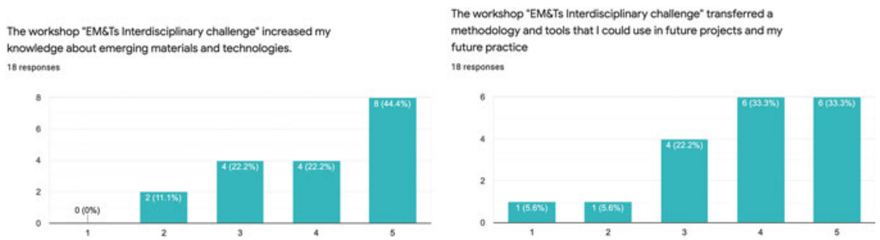


Fig. 21 Workshop feedback, charts 3 and 4

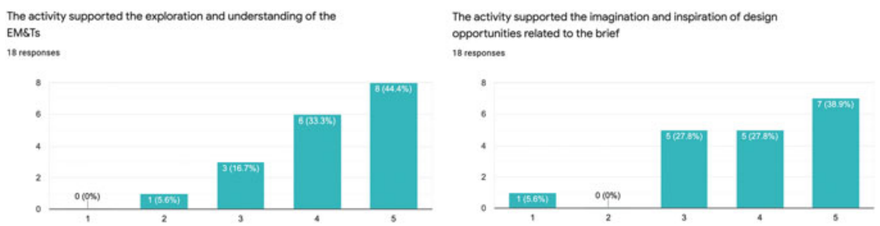


Fig. 22 Workshop feedback, charts 5 and 6

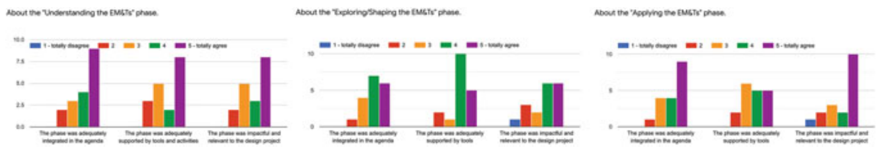
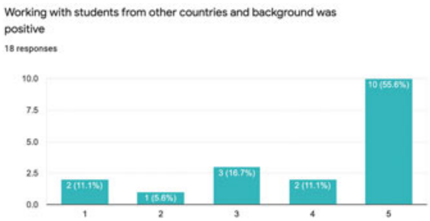


Fig. 23 Workshop feedback, charts 7, 8, and 9



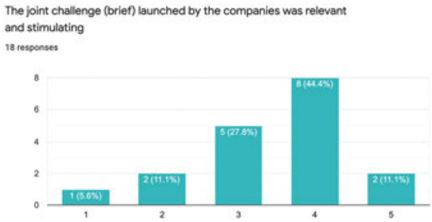


Fig. 24 Workshop feedback, charts 10 and 11

at the beginning of the workshop they had expectations to improve their material knowledge and at the end of the workshop they realized they received a lot of input in this regard. Students acknowledged they learnt how to use the provided tools and methodology and they would apply them in future projects. Indeed, the knowledge transfer toolkits were identified as one of the most valuable sources of learning (chart 2, 55.6% of the participants, representing the second most mentioned item).

Timewise, students reported that they experienced that the initial phases—namely, Understanding—were too long before diving into the actual project and for this reason it was challenging for them to complete the project, given the constrained time frame. Hands-on activities were acknowledged by students as useful to support exploration and understanding of EM&Ts (chart 5, average = 4.17 on a scale from 0 to 5), and to facilitate imagination and inspiration of concept ideas (chart 6, average = 3.94 on a scale from 0 to 5). They expressed that by experiencing first-hand the EM&Ts through samples and tinkering, they were able to visualize how to integrate them into a project. However, some students expressed that they would expect more hands-on and prototyping activities. Indeed, the complexity of ICS Materials requires a more extensive preparation and lab resources to approach them in a way that makes it possible to produce a wide collection of samples and prototypes. The constrained time frame of the workshop represents a limit in this regard.

Students reported that while tools were provided to them to facilitate in the initial phases, not adequate tools were developed for the Applying phase (chart 9, average = 3.72 on a scale from 0 to 5, compared to average = 3.83 for Understanding phase in chart 7 and average = 4 for Exploring/Shaping phase in chart 6). However, students recognized the inspirational card for EM&Ts integration as a tool to use in different phases: to explore design opportunities during the exploration phase and to stimulate creativity during the ideation phase, i.e., in the development of the first concept ideas; for the components design in the finalization phase. It was generally welcomed as a tool useful to combine ICS Materials with other EM&T areas. Even though it is evident that in the workshop project, students did not combine more than two different areas—and three areas in one project, students confirmed they really do believe that this the inspirational card for EM&Ts integration is a tool that they would use for future projects and from which they could always get inspired. As a result of the use of this tool, integration with experimental wood-based materials and advanced growing materials encouraged the development of more environmentally sustainable solutions for ICS Materials, for example by using PHA, Ioncell, and Sulapac.

Multi-disciplinary and cross-cultural aspects in team making were also identified as a positive aspect (chart 10, average = 3.94 on a scale from 0 to 5), and as one of the most valuable sources of learning (chart 2, 44.4% of the participants, representing the third most mentioned item).

The brief was generally positively received (chart 11, average = 3.4 on a scale from 0 to 5) and identified as characterized by challenging and prominent social and technological issues. However, students expressed that the combination of the two materials in a wearable application limited the diversity of ideas between the groups. Instead, they would prefer more open challenges. Nevertheless, given the compressed timeframe of the learning experience, the teaching staff opted for a quite delimited design space.

The involvement of companies and design studios in an academic learning environment was highly appreciated. Also, students identified that the most valuable sources of learning were the design pills by the design studios (chart 2, 77.8% of the participants, representing the second most mentioned item), followed by materials expert researchers' presentation (chart 2, 44.4% of the participants, representing the third most mentioned item), and interaction (chart 2, 33.3% of the participants, representing the fourth most mentioned item). Students appreciated that they could see examples of how professionals apply their design methods and approaches and how they are applying EM&Ts to products. The positive result in knowledge transfer coming from the pairing of scholarly teaching and case studies from the professional field is evidenced here. In addition, students reported that even though the tools were very useful to have an introduction to the topic or a glimpse of inspiration for the project, the interaction with expert researchers of the teaching staff was necessary to really understand the topic and to dive faster into the project. On the other hand, companies expressed that this learning experience was an opportunity to get in touch with new content developed within the Academia, i.e., fulfilment of the knowledge transfer goal of this experience. Also, they expressed enthusiasm about the fresh and creative ideas students were able to generate and present to them, thanks to the provided learning environment and setup.

In conclusion, students were encouraged to take part in the challenge of ICS Materials' sustainable and smart inclusion into everyday life as a catalyst for social, environmental, and technological change. By applying these novel tools and emerging contents to train young and future designers we provided them with the knowledge and hands-on skills for systematic understanding and prototyping and generating capabilities and solutions to bring to society and to industry. This education and design experience is evidence of how much is relevant for design educators and researchers to develop and implement techniques to train design students as future professionals, by consolidating the knowledge triangle involving research, education, and industry, through cooperation between Academia and Industry. This workshop and the overall DATEMATS project advocate the urgency for Academia to develop teaching methods to transfer knowledge and skills about emerging materials and technologies so that young designers could be updated and could respond to the demand of the industry. In my opinion, this approach will create job and industrial opportunities for knowledge and technology integration, exploitation, and collaboration. Hopefully, once prepared and trained, former students themselves will transfer novel knowledge and an aware mindset that ultimately will positively contribute to fulfilling technological challenges, and mitigating and solving societal and environmental issues, today and in the near future.

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