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Perspective

Smart Textiles in Building and Living Applications: WG4 CONTEXT Insight on Elderly and Healthcare Environments

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Abstract: Over the past 30 years, the development of new technologies and especially of smart textiles has unavoidably led to new applications of traditional textiles in the built environment. Depending on special constructional needs (i.e., acoustic insulation, thermal insulation, shading system, etc.) or health monitoring and supporting needs (i.e., for patients with chronical disease, etc.), an increasing number of possible applications has been proposed to improve human well-being. This is especially the case for healthcare environments (like elderly or nursing homes, etc.), but also educational environments (like schools, etc.) where young or old customers can benefit from technological innovation in several ways. As an ongoing activity of WG4 members for the CA17107 "CONTEXT" European research network, this study presents a review on selected applications for building and living solutions, with special attention to healthcare environments, giving evidence of major outcomes and potentials for smart textiles-based products.

Keywords: textiles; smart textiles; new technologies; buildings; healthcare environments; health monitoring

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1. Introduction

Buildings comfort and pollution reducing systems is a topic taking arising importance. Researches and studies are developed to investigate the acoustic, thermal as well as the visual comfort of buildings and methods to improve comfort standards. In this context, specific needs of different target persons have to be explored: aging people mostly but even youngsters attending educational buildings. Traditional building textile materials include fibres that are mixed with concrete, fibreglass reinforcement meshes, insulators, etc. Textile architectures can typically cover permanent tensile structures based on polyester or glass fibre fabrics, with a plastic-based coatings and awnings generally supported by polyester or polyolefin fabrics, with or without coating, especially for gardening [1].

In the building and living sectors, one of the main concepts that is being explored is the zero-energy building, based on the improvement of the materials used, construction methods and architectural design. In this scope, the use of textile-based materials, such as composite structures, that can contribute to both the reduction of the raw materials used and lowering energy consumption, can be seen as a determinant factor in order to achieve this goal.

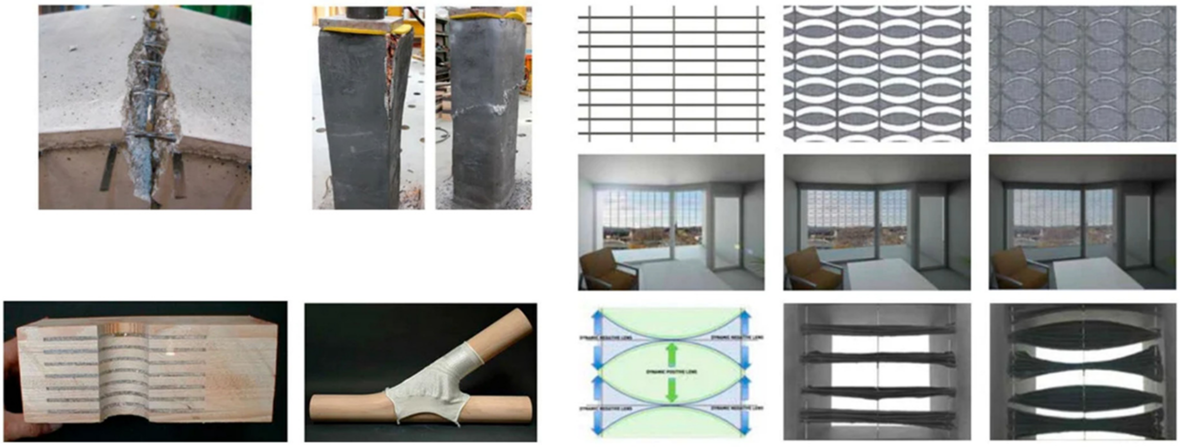
However, where are the building/architectural trends and healthcare tools going, thanks to continuous technological innovation and the availability of new solutions of "smart textiles"? What is the actual connotation and definition of smart textiles?

This review document aims at opening a discussion on recent trends, challenges, and gaps on the topic. More precisely, this presents selected review studies carried out from Working Group 4 "Building and Living" of EU-COST Action CA17107 "CONTEXT"—the European network to connect research and innovation efforts on advanced smart textiles (Horizon 2020) [2].

Principal features, applications, and challenges/gaps for the use of smart textiles, both in building components but also on customers, are discussed in following sections. In doing so, differing from earlier literature contributions, special care is given to smart textiles for healthcare environments, such as elderly homes, nursey homes, or even educational buildings, and smart textiles with specific application towards health monitoring for customers with special needs.

2. Background on Building Performance Indicators and Human, Health, Social Needs

Considering recent applications, there are no doubts that textiles can offer robust support for the development of enhanced and innovative solutions for building engineering and architectural applications (Figure 1). As far as building components and systems are taken into account, typical functions of both textiles and smart textiles can be conducted to insulation, shading, and even retrofitting of traditional constructional materials (see for example [3]).



(**a**) (**b**)

Figure 1. Examples of textiles and smart textiles: (**a**) construction retrofit; (**b**) smart shading. Figures reproduced from [3] under the terms and conditions of a Creative Commons CC-BY license agreement.

Generally speaking, worldwide researchers and producers recognize that "smart textiles" can be defined as those textiles which are able to sense, and thus react, to environmental conditions and external stimuli (i.e., mechanical, thermal, and chemical stimuli) thanks to a number of sensors incorporated in the textiles. One of the common strategies to obtain the best performance and multifunctionality of materials is using the biomimetic approach to optimize building constructions [4], architecture patterns [5], thermal insulation [6], heat dissipation systems [7], mechanical properties [8,9], and water and energy harvesting [10].

In this sense, healthcare environments—as far as they are intended as building systems—can take major advantage of a multitude of uses and smart textile solutions, which are expected to improve acoustic insulation, or thermal insulation, or shading functions, or even indoor air quality, etc.

In parallel, healthcare environments can gain a primary advantage from smart textiles as far as human needs are taken into account, and most importantly specific diseases are considered [11]. New technologies for addressing non-physical- (i.e., Alzheimer's, loneliness) and physical- (i.e., stroke, bedsores, and falls) related challenges are known to represent powerful tools. While there are no doubts about the primary role of textiles in supporting devices and components [12,13], the present review wants to open discussion on new design concepts [14], in which smart textiles are jointly used for multi-optimization purposes.

3. Smart Textiles for Buildings and Healthcare Environments

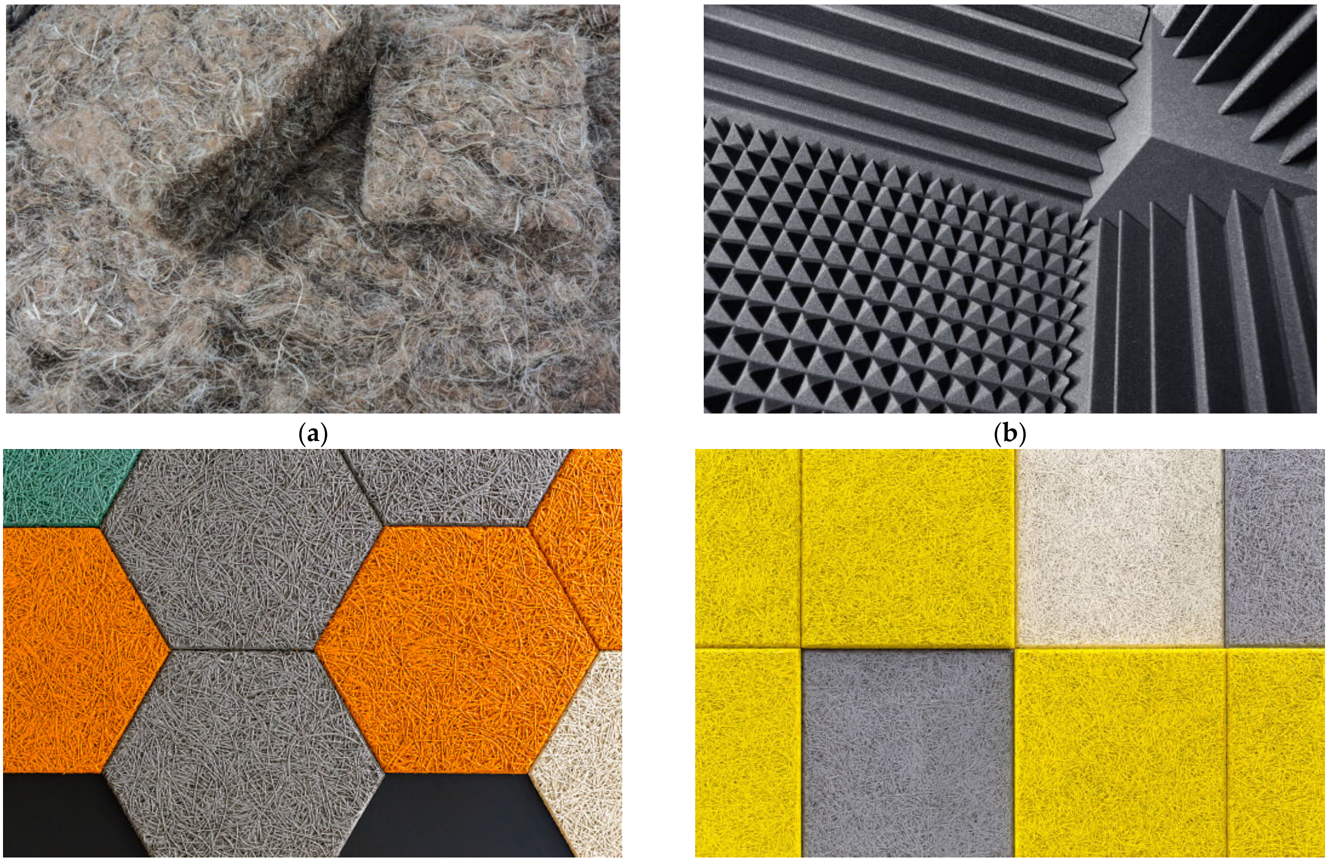
So far, textiles have been used for centuries to increase the quality of life of residents in the home environment and other living spaces. Textiles have been, for example, applied to furnishings, windows, and floors not only to control temperature, sunlight, and sound but also to offer pleasure through the colour, the texture and even the way of installing the fabric [3]. A multitude of literature examples also proved the efficiency of textiles for strengthening traditional constructional materials [15–18].

In this context, the development of smart textiles, since 1990, has unavoidably led to new applications of textiles in the built environment. Innovations in nanotechnology have attributed smart and active qualities to textiles increasing their use in architecture, especially in facades [19]. Nanomaterials enable textiles to function as a smart coating with self-healing, antimicrobial, anti-fouling, self-thermo-regulating, and other characteristics, thus contributing to increasing the sustainable qualities of the building. There is discussion on introducing textiles in architecture for signage within buildings, to provide a sustainable solution for producing ever-changing information combined with sounds and images [20]. Many of these applications of smart textiles are effective contributors of human-centred design principles that aim to improve the quality of life of end users. One of the most common applications of textiles affecting the indoor environmental quality is represented by electrospun nanofibres with sound absorbing characteristics, which can be used in architecture sound-proofing applications [21]. There is also an increasing development of smart textiles in the realm of safety, using sensors to detect vibration, sound, and movement to activate alarm systems. Additionally, in the realm of indoor pollution, smart textiles are proposed as tools to measure and filter pollutants and bacteria, thus contributing to indoor environmental quality improvement. Antioxidant and antibacterial smart textiles can be efficiently introduced into rooms in houses, with a new level of antibacterial and antioxidant systems that can help a person during sleep time [20]. There is thus an open discussion of applying smart textiles in the healthcare environment, to improve the quality of life of patients. Apart from the functional potential of smart textiles to aid architecture aspects of safety, way-finding and movement, there is the unexplored potential for contributing to the quality of life of patients by providing stimulation and engagement.

4. Applications, Potentials, Challenges for Buildings and Healthcare Environments

4.1. Acoustic Insulation by Natural Fibres and Textiles

The World Health Organization says that noise disrupts our rest and sleep, prevents customers from concentrating while working or studying, and this causes people in a noisy environment to become more upset, leading to deteriorating mental health, hypertension, and ischemic heart disease. Rooms in which people spend most of their lives must be well insulated both from the noise emanating from the environment and from its sources in the buildings. In the recent years, the European Commission has set a green and sustainable strategic direction, turning to natural raw materials found in nature, their processing, and use for the production of building materials [22,23]. Researchers of materials acoustics are also interested in various natural fibres and textile waste, as well as such acoustic materials that are gradually finding their niche in the market. Composite materials are developed using natural fibres from hemp, coconut, and reed, as well as sludge boards (Figure 2).



(a) (b) (c) (d)

Figure 2. Examples of possible solutions for acoustic insulation: (**a**) hemp isolation material; (**b**) textile acoustic panels; (**c**) wool acoustic panels; (**d**) synthetic textile waste panels.

Acoustic panels combine in general micelles and recycled textiles. Acoustic wall panels, partitions, and ceilings are made from recycled plastic bottles, or new acoustic materials are created by recycling cotton and cellulose [22]. From a technical point of view, the development of panels from textile fibres and waste textile materials poses an open problem, because the desired ratio of sound absorption to panel strength must be achieved [22]. To get the board to absorb sound well, the porosity of the board must be properly increased. However, increasing the porosity reduces the strength of the plate and makes it particularly brittle.

Recently, based on increasing sustainability needs for buildings and components, a considerable number of research efforts have been focused on the use of recycled textiles for acoustic (and even thermal) insulation systems [24,25]. The potential of industrial waste nonwoven polyester textile has been also addressed in [26] in terms of sound absorbing capacity, thermal conductivity, and also reaction to fire.

Residents of apartment buildings often suffer from the noise from other floors and the neighbours. The vibrations, bumping, and shouting of neighbours can cause severe discomfort and even health problems. There are a number of companies who have developed a unique acoustic technology—acoustic panels made of fungal micelles and recycled textile waste. This is one of the first projects of its kind to be commercialized. Acoustic panels are made of soft, foam-like mushroom materials. Acoustic panels in natural light tones stand out with their elegant velvet finish and 3D relief for better sound absorption [27].

In order to successfully carry out the acoustic redevelopment of old, first-generation apartments, it is necessary to evaluate the existing indoor noise environment, identify problem areas and eliminate the main identified sources of noise, such as shock and plumbing noise [28]. After listening to residents living in old apartments, the following problems became clear: the noise of a high-weight floor impact and plumbing.

Various fibres are used to strengthen concrete, improving the properties of cement. Textile or mineral wool inserts with acoustic properties provide an aesthetically attractive and functional finish, improve the acoustics of the space, and absorb noise in the room. A critical analysis is reported in [29,30]. In terms of natural fibres, bamboo coir and jute are analysed. Also, the effect of alkali present in cement mixture on the degradation of natural fibres is detailed. Critical observations such as changes in crack patterns, the effect of the nature of fibres, and the environment in which they are reinforced is then discussed. For example, the use of different sealing materials for hydrophobic fibres has direct consequences on the ultimate property of reinforced concrete. In terms of synthetic fibres, predominantly used solutions in such reinforcements—such as polypropylene (PP), polyethylene (PE), and nylon (PA6)—have also specific features. The fibre–matrix interface studies is discussed and further research areas are suggested.

Modern technologies for acoustics and noise reduction are typically represented by wood wool acoustic panels/multifunctional solutions (Figure 2). Wood and wool panels are suitable for use where environmental preference is a priority. They are made of simple, natural materials, such as wool, wood or cement, are of high quality, inexpensive and, most importantly, absorb sound well. Such panels not only protect well from noise, but also embellish the interior. It is for example claimed that sheep's wool can absorb up to 30% of its weight in moisture without losing any insulating properties. Wool also has another advantage—with higher humidity and condensate content, due to its unique properties, its protein fibre does not create conditions for mould to breed [30]. They also absorb echoes and do not release heat from the premises [31]. Acoustic panels are most suitable for large rooms with high ceilings or industrial spaces adapted for offices. They effectively absorb sound, form cosy spaces and complement interior design solutions. Since this material absorbs sound from both sides, it protects against noise twice as well. The system of acoustic panels can consist of wall panels and their great advantage is a wide range of different colours, sizes, and shapes (see Figure 2 and [30]).

Acoustic partitions dividing the space on the floor also help to absorb the sound. They are light, flexible, made of softer material and can be easily transferred from one place to another. In addition, they are easy to assemble or disassemble, according to special needs [23].

Currently, hemp concrete, which is characterized by a high-volume ratio of added hemp fibres, is used in buildings and it is gaining popularity (Figure 3 and [31,32]). Unlike other substances, hemp concrete does not wear with age, but only strengthens. It contains some CO_2 locked inside, in the form of hemp fibres, and because organic compounds stay locked into its matrix, the release of CO_2 from hemp decaying cannot occur.

Another very important aspect is that hemp concrete has antiseptic properties. Lime, which is an integral part of the said concrete, has the same characteristics. It is also important to mention the fact that rodents do not come into a hemp house, and insects do not breed in it. Such a house also breathes; it does not need to be covered with steam-insulating films.

Whoever has asthma and other respiratory problems, would be wise to choose to build a hemp concrete house. It is worth noting that hemp concrete is not combustible. Since hemp fibre shives are soaked in lime, this substance practically does not burn [32].

4.2. Acoustic Insulation by Nanofibrous Layers and Textiles

In 2017, the Next Technology Tecnotessile (NTT) research centre supported an Italian technical textile company in the implementation of a project aimed to improve the acoustics in classrooms and healthcare environments [34]. Many schools in Italy are hosted in historic buildings, and for this reason are affected by poor sound comfort. The concept of the innovative solution for the improved acoustic performance lay in pre-defined absorbing panels supported by novel nanofibrous layers, which, thanks to a specific surface, porosity, and tortuosity, allow the reduction of the energy of sound waves. It was designed as a complete kit for the acoustic correction of the classrooms, which could be installed on site by the members of the school environment (teachers, pupils), avoiding wasted time and costs for the involvement of professionals. The choice of the right kit and the expected effectiveness in terms of performance acoustics are based on a device made within the project that, given the sound source and the size of the classroom, or in any case of the environment under consideration, proposes the most appropriate solution in terms of the number of panels and related positioning.

(**a**) (**b**)

Figure 3. Example of (**a**) hemp blocs and (**b**) positioning of hemp concrete (reproduced from [33]).

The activity focused on the development of innovative solutions to increase the acoustic performance of sound-absorbing panels and further nanotechnological functionalization, necessary both for the final application sector and for any new markets, by producing nanofibrous layers. Today, these nanomaterials find application in industries such as textiles, electronics, catalysis, and filtration. However, some recent studies highlight their possible benefits in terms of sound absorption. The parameters that describe the effectiveness in terms of sound absorption are typically density, porosity, and geometry. Such a set of aspects are intrinsic to the morphology that non-woven nanofibres assume with the electrospinning process. Features like the completely random distribution, the high volume/surface ratio, and the considerable porosity, are in fact optimal factors for the increased acoustic performance of panels. Among the solutions which are known to the literature as "electrifiable", the attention goes to polyamide (PA6), polyfluoride-polyvinylidene (PVDF), and other polyesters.

An experimental investigation has been carried out for the optimization of recycled polyester electrospinning. This activity required particular attention to the optimization of process parameters, as the material undergoes a phase of degradation that alters and worsens intrinsic properties, such as the collapse of the average molecular weight of polymer chains. An extended study followed for the functional characterization of the panels made by coupling conventional materials with PVDF nanofibrous layers. The instrument used for the characterization and comparison of the materials is the "Kundt tube" (Figure 4 and [34]).

The Kundt tube realized for the NTT project was used to measure, according to ASTM E2611, the so-called "transmission loss", i.e., the share of sound absorption in transmission. Thanks to the use of the fabric outside the acoustic panel, it was possible to protect the nanostructured layer from any areas of imperfect adhesion by inserting the nanofibres inside the panel/fabric sandwich. The new systems were made from non-woven textile structures in polyester of different thicknesses and densities depending on the specific use. Textile structures made using non-woven production technologies were superficially modified by smoothing and printing processes. The experiments involved the development of surface treatments of non-woven panels by thermal and physical-mechanical processes and subsequent printing processes to achieve optimal aesthetic quality, to be used at sight. It was possible to validate the new material consisting of non-woven wadding—nanofibres—that responded well to the requirements for an application in the technical field of acoustics. In particular, maximum acoustic performance was achieved by using low-thickness panels while greatly reducing the volume of nanofibre-free components. With the introduction of a textile matrix that remains on the outer side of the prototype it was also possible to work on a series of chemical finishing treatments for the introduction of additional technical properties.

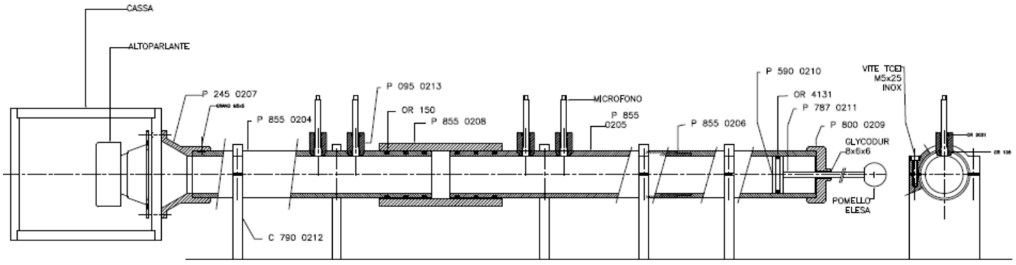


Figure 4. Layout of "Kundt tube" developed in NTT funded research project.

As mentioned above, it was chosen to couple the sound-absorbing materials to a thin, non-woven textile. For self-cleaning and sanitization of the interior spaces, a formula containing inorganic photoactive nanofillers was developed, and the application was made. This finishing is capable, when activated by the UV component of light, to generate hydroxyl radicals capable of degrading stains and any harmful compounds as bacteria.

In general, a homogeneous distribution of materials on the surfaces of the room is preferable in sound absorbent classrooms, where panels have to be placed at an adequate height from the ground. Sound reverberation correction was achieved in the pilot classroom through the application of sound-absorbing and acoustically reflective panels, gaining an optimal reverberation time.

4.3. Acoustic and Thermal Insulation by Phase Change Materials (PCM) and Textiles

The phase change materials (PCM) are known for the ability to absorb or release energy required for heating or cooling. PCM can be encapsulated in electrospun fibres [35]. Most commonly, PCMs are various paraffins, oils, fatty acids, or ionic liquids [36,37]. If the electrospun fibres are well designed they have great thermal management ability [35] especially for energy storage applications [38], thermal insulation [13], and thermal comfort [39]. Thermo-physiologically comfortable clothing supports the thermoregulation of the body and helps the wearer to keep a comfortable temperature. The thermal properties can also be achieved by biomimicry of natural materials [40] as the high surface area and porosity are desired in thermal and sound insulation [41,42].

The acoustic insulation in the current regulations and European Union policies requires novel material. We need more environmentally friendly, lighter, and thinner absorbers that meet the best acoustic performance specifications. The typical materials are composites based on fibreglass or mineral wool, but still have durability issues. The design and fabrication of composite fibrous materials with multifunctional interior core structures are increasingly attractive because of the incorporation of different inside materials. One of them is electrospun fibres, having the great advantage of designing composite fibres with multifunctionality by constructing, for example, core–shell fibres. The incorporation of non-Newtonian or shear thickening fluids exhibits increased energy dispensation on impact or the ability to damp sounds. The core–shell fibres have a greater sound-absorbing ability than the single-phase fibres. One of the typical core materials used in co-axical electrospinning is polyethylene glycol (PEG), especially for low frequency sounds [43]. Low frequency sounds include car or aircraft engines, but also many electronic and medical devices often used in homes for the elderly [44]. The electrospun fibres showed great resistivity for acoustic wave flow [45] and enhancement of sound transmission loss [46].

4.4. Smart Textiles for Indoor Air Quality Improvement

Indoor air quality, as known, is strongly affected by indoor materials, such as carpet and cloth, which may act as sources or sinks of gas-phase air pollutants. In this regard, smart textiles can efficiently contrast the typical phenomena of degradation and aging of traditional materials, with direct effects on air quality levels and improvements.

The review study in [47] reports that the associations between ozone concentrations measured outdoors and both morbidity and mortality may be partially due to indoor exposures to ozone and ozone-initiated oxidation products. It is observed that indoor exposures to ozone and its oxidation products can be efficiently reduced by filtering ozone from ventilation air and limiting the indoor use of products and materials whose emissions react with ozone. It is thus clear that such steps might be especially valuable in schools, hospitals, and childcare centres in regions that routinely experience elevated outdoor ozone concentrations.

Lakey et al. [48] emphasized the importance of quantifying the impact of clothing on ozone–human interactions and indoor air quality. As such, the authors developed a kinetic multilayer model of surface and bulk chemistry of the skin, which includes mass transport through the skin and chemical reactions of skin lipids and ozone in the skin and secondary chemistry in the gas phase (Figure 5).

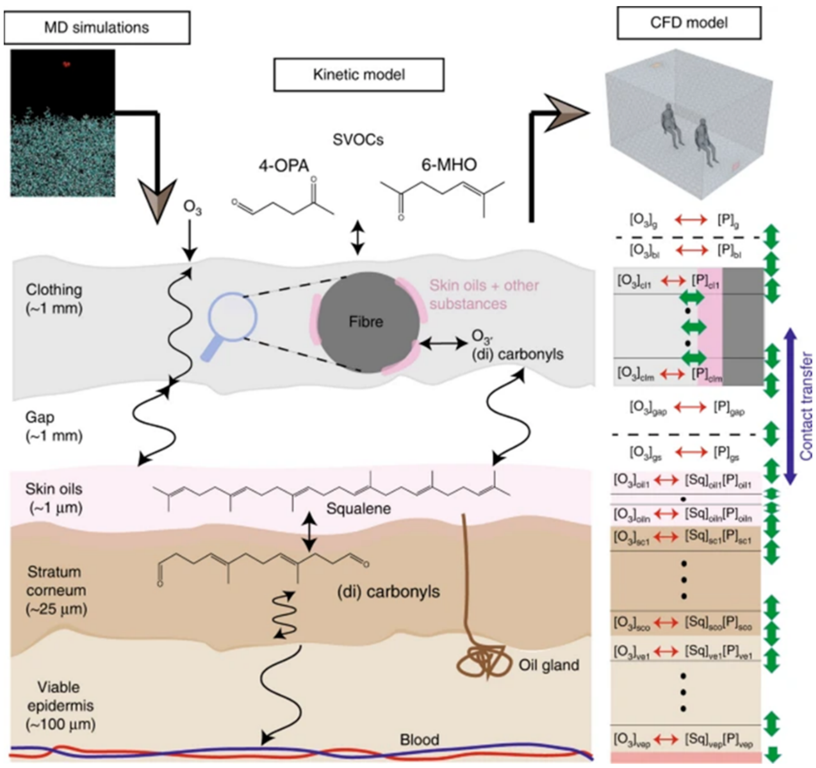


Figure 5. Schematic representation of the kinetic multilayer model developed in [48] for skin–cloth–ozone interactions. Figure reproduced from [48] under the terms and conditions of a Creative Commons license agreement.

Textiles and fibres in carpets have a key role in terms of indoor air quality in the same order of clothes. The study presented in [49], in this regard, investigates the behaviour and potential of different solutions for carpets against ozone. The comparative study in [49] indicates that carpets are good sinks for ozone with potential to lower harmful ozone levels indoors. On the other hand, carpets can emit significant levels of volatile organic compounds, and these emissions can be amplified in the presence of ozone. Special attention is hence required for dedicated healthcare housing or educational applications.

In [50], a new technological textile has been proposed and investigated, based on TiO_2 nanoparticles and optical fibres, for the degradation of pollutants potentially existing in the indoor air of hospitals. As shown, the use of such technology for the treatment of indoor air, not only in hospitals but also in various other sectors, looks very promising and is expected to be deepened in the near future. In addition, the study confirms that using optical fibres can be extremely efficient in the inactivation of microorganisms present in air, and thus in the degradation of different types of air pollutants.

The study presented by Zhu et al. [51] investigated an effective and environmentally friendly technology, which has been introduced to reduce the malodours from textiles. Results suggest that the proposed solution can play a significant role in the removal of various smells. Thus, it has the potential to clean the indoor environment from odour pollution, and this is particularly of interest for healthcare and educational applications. Given such a high potential for deodorization, the same technology may also be used in a wide range of fields including wastewater odour treatment in the chemical or the livestock breeding industry.

4.5. Smart Shading Devices

According to several literature studies, there is evidence that immobility and a lack of physical activity are widespread issues among seniors over the age of 65. Long durations of not leaving the house may increase mortality risk, social isolation, depression, cognitive impairment, and other health issues. Going out of the house, even just to spend some rest time outside, can indeed improve mental health, increase levels of vitamin D, and provide opportunities for participation in a variety of activities such as psychosocial, emotional, cultural, therapeutic, leisure, or even physical activity, since resting is an important part of physical activity for some seniors [52].

According to specific findings from Taiwan, for example, old adults who live near greenways with high levels of neighbourhood social capital and high-quality routes, natural components, and seats, engage a lot in outdoor activities [53].

Studies conducted in Madrid showed that old adults represent 26.35% of the users of outdoor public spaces (like parks, squares, streets, etc.). However, their decision to stay in those places depends mostly on environmental variables, such as mean radiant temperature and air temperature [54]. One of the solutions supporting the presence of old adults outdoors is creating shaded spaces. Results from Turkey confirm that outdoor shaded places provide a better microclimate during hot and dry summers, as well as a social space boosted by pleasant conditions [55]. The impact of a shade is significant, which can be confirmed by thermovision measurements. In Polish conditions during the summer period, the difference in the temperatures of two benches in an urban park exceeded 17 °C [56], which influenced the comfort of users of the public space.

The shading function, increasing the quality of life of old people, could be served by smart textiles. First of all, they can offer shade for the space underneath (as in shading sails, see Figure 6), and at the same time have additional functions, such as, for instance, energy production from solar radiation.

For example, perovskite solar cells are a promising photovoltaic technology solution. There has been limited research into 3D (wire-shaped) flexible perovskite solar cells. Through composite integration, more work is needed to actualize technologies such as self-powering woven textiles and multifunctional materials [57]. However, some studies have proved that on the lab scale, perovskite solar cells present high power conversion efficiency, simple device fabrication, all solid-state structure, and the possibility to integrate traditional devices into a fibre format [58]. All experiments with perovskite solar cells showed that by now this solution is recognized as a strong contender for next generation photovoltaic technology [59]. The other alternative could be to use photo-thermoelectric textiles, which were already analysed as solar energy source in the case of clothes, [60,61] or combined solutions integrating different technological approaches [62].

Regardless of the technology adopted, in the case of shading sails made of smart textiles, there is no need to struggle with the typical technical difficulties which can be found when introducing smart textiles into clothes (i.e., with comfort and wearability challenges), [63]. This makes production easier on an industrial scale. An open question is how the produced energy could be used: outside or inside a nursing home. Considering that some studies focus directly on the preferences of old adults on the outdoor environment in nursing homes [64], future studies could analyse how this specific community cooperates with smart shading sails, including comfort or a sense of security.

Figure 6. Example of shading sails (Elche, Spain). Photo © Jan Kazak.

5. Applications, Potentials, Challenges for Life Quality Improvement

5.1. Smart Textiles for Health Monitoring

Among many elderly people, seeking comfort and an independent lifestyle are key reasons for using health monitoring or smart home systems. In particular, the shortage of hospitals and nursing facilities opens new development opportunities for smart textile technologies and intelligent sensors. One of them is pressure sensitive mats used in bedding to signify any physiological conditions, indicating movements and respiratory rates or alternating pressure on different parts of the body [65]. The COVID-19 pandemic also resulted in enormous development in protective clothing [39,66,67], especially in protective face masks [68,69].

Electrospun polymer membranes are excellent materials owing to their versatility, tremendous range of possible physic-chemical properties, and their tunability. Electrospun membranes are very useful for any biosensor applications, especially concerning health monitoring. The biosensors consist apart of the bifunctional membrane of transducers for biological substances detection, where the sensing comes through substances recognition process, and transducer converts it into output signals. Here, the electronic devices can be incorporated to textiles and membranes and act as skin-like sensors. The electrospun membranes give high permeability and flexibility [70]. One of the expanding technologies based on textiles are triboelectric nanogenerators (TENG), which can capture the energy from the charges generated at the fibres' surfaces by motion [71].

There are also some nanogenerators (NG) that are able to harvest energy from the environment via mechanical, thermal or other processes [72]. An example of incorporating nanotechnology based on electrospun fibre yarns in a real-life, smart textile applications, showcasing both the energy harvesting and motion sensing potential of the triboelectric yarn, is presented in Figure 7. The smart textile application is demonstrated for wearable and implantable devices based on the ore–shell structure of carbon nanotubes (CNT) yarn and electrospun PVDF fibres [73].

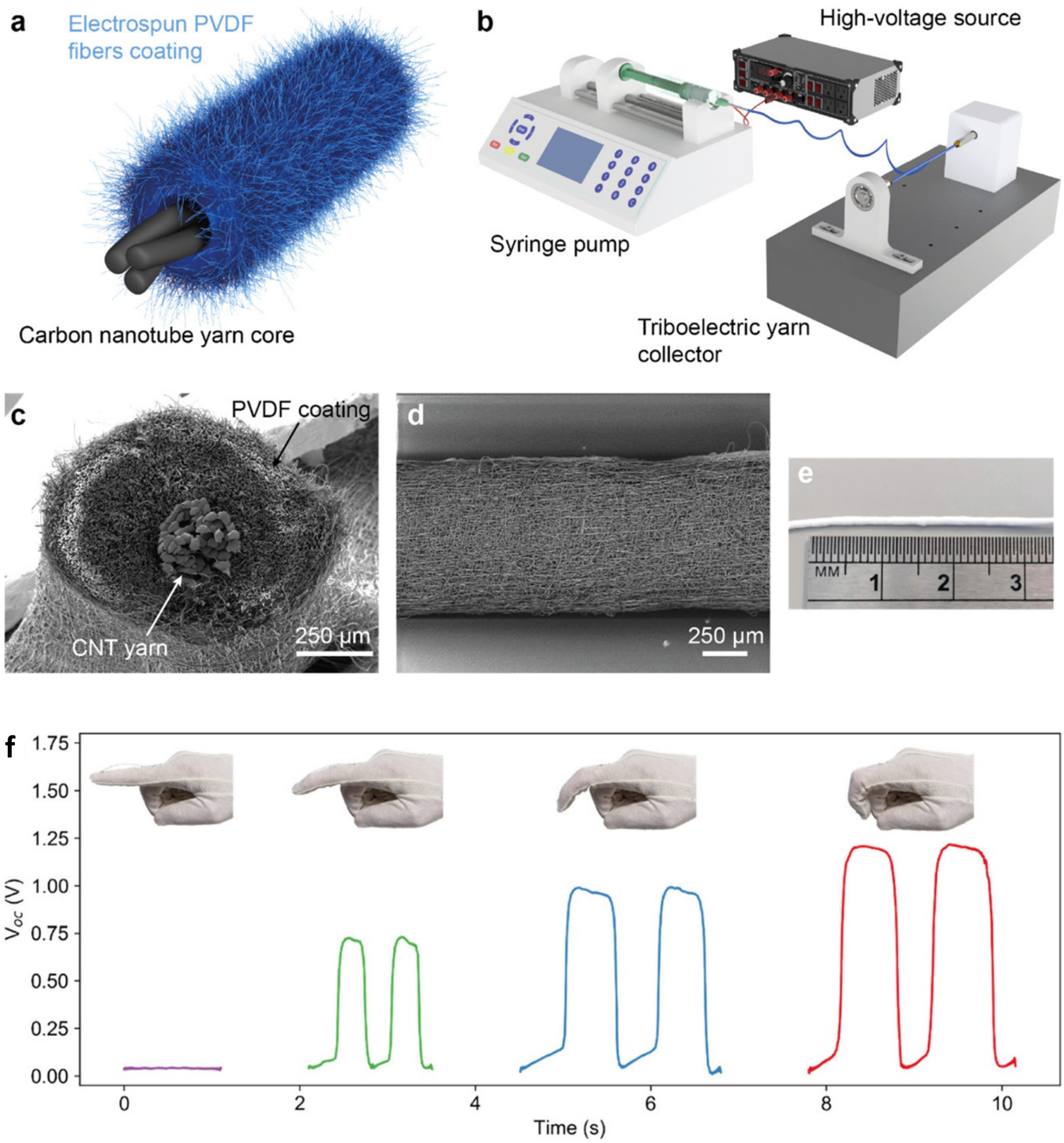


Figure 7. Triboelectric core–shell structure of yarns: (**a**) scheme of the yarn; (**b**) fabrication setup of yarn, including electrospinning setup and rotating collector; (**c**,**d**) SEM micrographs of the cross section and along the yarn; (**e**) image of triboelectric yarn above the ruler; (**f**) demonstration of the triboelectric yarn in a glove with the output measured as the haptic potential. The yarn (5 cm in length) was attached to the index finger of the glove. All figures are reproduced from [73] under the terms and conditions of an open access CC-BY license agreement.

While electrospinning is basically a fibre formation technique, which uses electrostatic forces to draw ultrafine fibres from a wide variety of polymers to create smart and hybrid fibres featuring piezoelectric, triboelectric, or multi-responsive mats. In electrospinning, high voltage is applied to the polymer solution that is typically pushed through a stainless-steel nozzle. Both type of voltage polarities can be applied to the nozzle and counter electrode, usually a collector in various configurations [74]. Due to the electrostatic forces, the polymer solution forms the cone jet [75] and charges distribute at the liquid interface, causing the spinning and stretching of the polymer jet [76]. During this process solvents evaporate and the solid fibres are produced [77], typically in random arrangements as a nonwoven membrane with porosity reaching above 90% [78]. All the parameters affecting the morphology and properties of electrospun fibres can be found in [79–81].

The collectors used for the deposition of fibres [82] allows the creation of 3D structures [83], not only for biomedical applications [84–86] but also for water [10,87–90] and energy harvesting [73,91,92]. However, modifying the physic-chemical properties of polymers may go along with an undesired change in their mechanical properties [93,94].

5.2. Smart Textiles for Life Quality Improvement in Dementia Disease

According to the literature, it has been proved that wearable textile sensors can benefit the home monitoring of several chronic diseases, including dementia [95,96] (Figure 8). There are today also new possibilities to incorporate smart textiles as large area displays with sensors and activators, that could be involved in the built environment (to serve as safety detectors), to enable way finding, and serve as functional communication tools thus improving the health care environment [97].

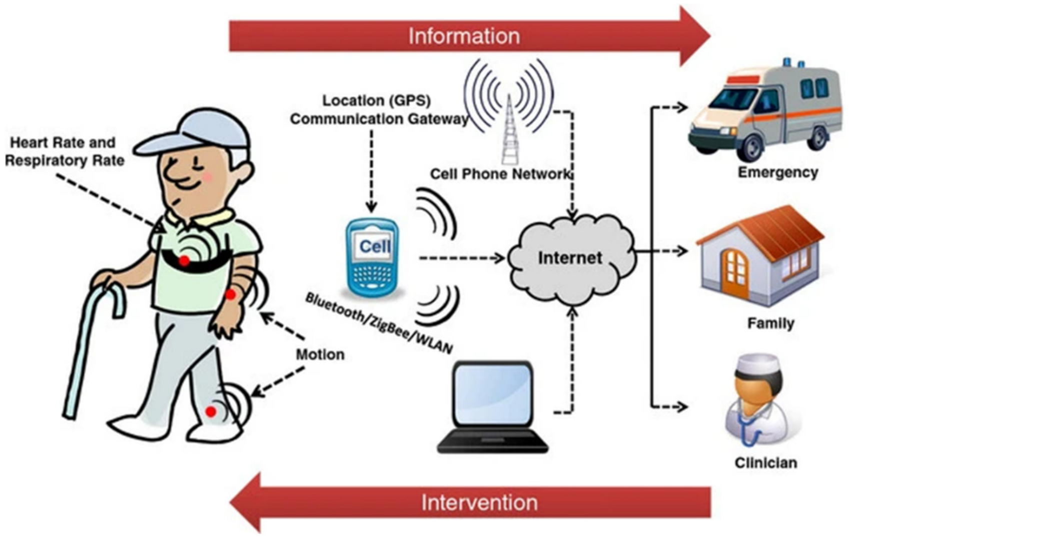


Figure 8. Illustration of a remote health monitoring system based on wearable sensors. Health-related information is gathered via body-worn wireless sensors and transmitted to the caregiver via an information gateway such as a mobile phone. Caregivers can use this information to implement interventions as needed. Figure reproduced from [96] under the terms and conditions of a Creative Commons CC-BY license agreement.

The purpose of the design is to develop through active textile designs and products that stimulate the senses, promote positive emotions, and offer comfort in both individual and social contexts. The design community is facing the challenge of developing custom products aimed at people with dementia, as global population aging is observed. It is important to demonstrate the benefits of creative design through research and development for old people. It is a challenge for social care providers to focus on prosperity and well-being, and not just on medical care. Through research, it seems that design solutions are urgently needed that can help the elderly and especially those suffering from dementia, to live well and enjoy life.

One current open challenge is, among others, the assessment of the possibilities of smart textiles in the care home environment for people living with dementia. Many old people, after a prolonged period of institutionalisation, feel lonely, socially isolated, and bored, and they are exposed to the risk of developing depression. The potential of a nursing home as a therapeutic resource is increasingly recognised through research on the impact of design and other environmental features and practices that support independence, enhance personal identity, and enhance quality of life. Other non-clinical practices that have been shown to be beneficial to the well-being of people with Alzheimer's and other related diseases include multi-sensory stimulation environments.

There is a growing body of research in the use of textiles including multi-sensory and e-textiles for care home residents, mostly as aprons, cushions, and small size objects, but this research is mostly focused on producing and evaluating objects for handling [98,99], see Figure 9.

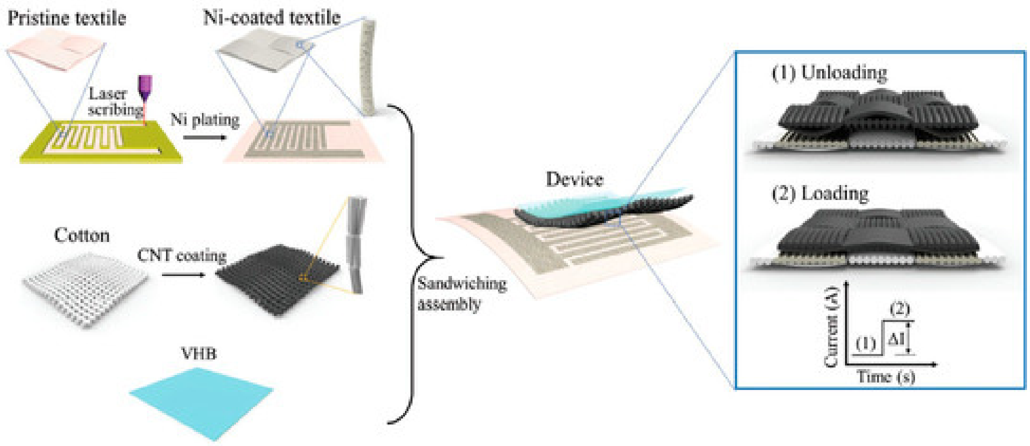


Figure 9. Detail example for the fabrication of textile pressure sensor based upon nickel (Ni) and carbon-nanotube-coated textiles. Figure reproduced from [99] under the terms and conditions of a Creative Commons CC-BY license agreement.

The use of smart textiles in interior architecture as multi-sensory stimulators, in this regard, looks like a promising solution that could engage people with dementia, thus increasing their quality of life. Smart textiles can appeal to the senses that are remaining active even in the last stages of dementia by providing auditory, visual, haptic, and other sensory stimulation as, for example, through vibration and light electro stimulation. Using large displays of smart textiles as part of the interior design or incorporated within furniture and soft furnishing, but also in especially designed art-sculptures, could provide a source of interactive engagement, thus increasing communication, pleasure, and consequently the quality of life of people living with dementia.

6. Conclusions

Over the decades, the development of new technologies, and especially smart textiles, has unavoidably led to new applications of traditional textiles in the built environment. Depending on special constructional requirements (i.e., acoustic insulation, thermal insulation, shading systems, indoor air quality improvement, etc.) or health monitoring and supporting needs (i.e., for patients with chronical disease, etc.), an increasing number of possible applications has been proposed. For instance, the use of smart textiles in interior architecture as multi-sensory stimulators is a promising solution that could engage people with dementia, thus increasing their quality of life. Using large displays of smart textiles incorporated in especially designed art-sculptures could provide a source of interactive engagement, thus increasing communication, pleasure, and consequently the quality of life of people living with dementia.

Smart textiles can also be efficiently used for improving the air quality in indoor atmospheres and contrast the typical phenomena of degradation and aging of traditional materials, with direct effects on air quality levels, especially in hospitals, nurseries, schools, and elderly and healthcare environments. Textiles and fibres in carpets as well as in clothes have a key role in terms of indoor air quality for special application in healthcare buildings, improving human well-being.

Another important point concerning the use of textiles in building is the shading function of smart materials increasing the quality of life of old people.

In conclusion, in this paper, as an ongoing activity of WG4 members for the CA17107 "CONTEXT" European research network (Horizon 2020), a review on selected applications for building and living solutions was presented and discussed with literature support, with special attention to healthcare environments, giving evidence of major outcomes and potentials for smart textiles-based products.

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References

1. Echeverria, C.A.; Handoko, W.; Pahlevani, F.; Sahajwalla, V. Cascading use of textile waste for the advancement of fibre reinforced composites for building applications. *J. Clean. Prod.* **2019**, *208*, 1524–1536. [CrossRef]
2. CONTEXT. CA17107—European Network to Connect Research and Innovation Efforts on Advanced Smart Textiles. 2017. Available online: https://www.context-cost.eu/ (accessed on 6 November 2022).
3. Bedon, C.; Rajčić, V. Textiles and Fabrics for Enhanced Structural Glass Facades: Potentials and Challenges. *Buildings* **2019**, *9*, 156. [CrossRef]
4. Prabhakaran, R.T.D.; Spear, M.J.; Curling, S.; Wootton-Beard, P.; Jones, P.; Donnison, I.; Ormondroyd, G.A. Plants and architecture: The role of biology and biomimetics in materials development for buildings. *Intell. Build. Int.* **2019**, *11*, 178–211. [CrossRef]
5. Gruber, P.; Imhof, B. Patterns of Growth—Biomimetics and Architectural Design. *Buildings* **2017**, *7*, 32. [CrossRef]
6. Zhao, Y.; Fang, F. A Biomimetic Textile with Self-Assembled Hierarchical Porous Fibers for Thermal Insulation. *ACS Appl. Mater. Interfaces* **2022**, *14*, 25851–25860. [CrossRef] [PubMed]
7. Zuazua-Ros, A.; Martín-Gómez, C.; Ramos, J.C.; Gómez-Acebo, T. Bio-inspired Heat Dissipation System Integrated in Buildings: Development and Applications. *Energy Procedia* **2017**, *111*, 51–60. [CrossRef]
8. Fratzl, P. Biomimetic materials research: What can we really learn from nature's structural materials? *J. R. Soc. Interface* **2007**, *4*, 637–642. [CrossRef]
9. Stachewicz, U. Microstructure study of fractured polar bear hair for toughening, strengthening, stiffening designs *via* energy dissipation and crack deflection mechanisms in materials. *Mol. Syst. Des. Eng.* **2021**, *6*, 997–1002. [CrossRef]
10. Knapczyk-Korczak, J.; Szewczyk, P.K.; Ura, D.P.; Bailey, R.J.; Bilotti, E.; Stachewicz, U. Improving water harvesting efficiency of fog collectors with electrospun random and aligned Polyvinylidene fluoride (PVDF) fibers. *Sustain. Mater. Technol.* **2020**, *25*, e00191. [CrossRef]
11. Oatley, G.; Choudhury, T.; Buckman, P. Smart Textiles for Improved Quality of Life and Cognitive Assessment. *Sensors* **2021**, *21*, 8008. [CrossRef]
12. Blaylock, A.; Constantin, F.; Ligabue, L.; Bocaletti, L.; Siroka, B.; Siroky, J.; Wright, T.; Bechtold, T. Caregiver's vision of bedding textiles for elderly. *Fash. Text.* **2015**, *2*, 6. [CrossRef]
13. Gerhardt, L.-C.; Lenz, A.; Spencer, N.D.; Munzer, T.; Derler, S. Skin-textile friction and skin elasticity in young and aged persons. *Ski. Res. Technol.* **2009**, *15*, 288–298. [CrossRef] [PubMed]
14. Yao, M.; Li, L. Design Thinking Applied to Home Textiles Innovation: A Case Study in an Elderly Centre in Hong Kong. *Designs* **2022**, *6*, 49. [CrossRef]

15. Bournas, D.A.; Triantafillou, T.; Zygouris, K.; Stavropoulos, F. Textile-Reinforced Mortar versus FRP Jacketing in Seismic Retrofitting of RC Columns with Continuous or Lap-Spliced Deformed Bars. *J. Compos. Constr.* **2009**, *13*, 360–371. [CrossRef]
16. POLYMAST Project, 2011. Polyfunctional technical textiles for the protection and monitoring of masonry structures against earthquakes. Final report. Transnational access within the SERIES project: SEVENTH FRAMEWORK PROGRAM capacities specific programme research infrustructures (project No.: 227887).
17. Bournas, D.A. Concurrent seismic and energy retrofitting of RC and masonry building envelopes using inorganic tex-tile-based composites combined with insulation materials: A new concept. *Compos. Part B Eng.* **2018**, *148*, 166–179. [CrossRef]
18. Furtado, A.; Rodrigues, H.; Arêde, A.; Varum, A. Cost-effective analysis of textile-reinforced mortar solutions used to re-duce masonry infill walls collapse probability under seismic loads. *Structures* **2020**, *28*, 141–157. [CrossRef]
19. Jalil, W.D.A. Smart textiles for the architectural façade. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2020; Volume 737. [CrossRef]
20. Oliveira, A. Smart Textile for Architecture: Living with Technology, Advances in Intelligent Systems and Computing Human Interaction, Emerging Technologies and Future Applications II. In Proceedings of the 2nd International Conference on Human Interaction and Emerging Technologies: Future Applications (IHIET—AI 2020), Lausanne, Switzerland, 23–25 April 2020.
21. Priniotakis, G.; Stachewicz, U.; van Hoof, J. Smart textiles and the indoor environment of buildings. *Indoor Built Environ.* **2022**, *31*, 1443–1446. [CrossRef]
22. Gounni, A.; Mabrouk, M.T.; El Wazna, M.; Kheiri, A.; El Alami, M.; El Bouari, A.; Cherkaoui, O. Thermal and economic evaluation of new insulation materials for building envelope based on textile waste. *Appl. Therm. Eng.* **2019**, *149*, 475–483. [CrossRef]
23. Gravagnuolo, A.; Angrisano, M.; Girard, L.F. Circular Economy Strategies in Eight Historic Port Cities: Criteria and Indicators Towards a Circular City Assessment Framework. *Sustainability* **2019**, *11*, 3512. [CrossRef]
24. Briga-Sá, A.; Nascimento, D.; Teixeira, N.; Pinto, J.; Caldeira, F.; Varum, H.; Paiva, A. Textile Waste as an Alternative Thermal Insulation Building Material Solution. *Constr. Build. Mater.* **2013**, *38*, 155–160. [CrossRef]
25. Binici, H.; Eken, M.; Dolaz, M.; Aksogan, O.; Kara, M. An environmentally-friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. *Constr. Build. Mater.* **2014**, *51*, 24–33. [CrossRef]
26. Antolinc, D.; Filipič, K.E. Recycling of Nonwoven Polyethylene Terephthalate Textile into Thermal and Acoustic Insulation for More Sustainable Buildings. *Polymers* **2021**, *13*, 3090. [CrossRef] [PubMed]
27. Iașnicu, I.; Vasile, O.; Iatan, R. Thickness influence on absorbing properties of stratified composite materials. *J. Eng. Stud. Res.* **2015**, *21*, 28–34. [CrossRef]
28. Oh, Y.K. An assessment model for the indoor noise environment of aged apartment houses. *J. Asian Archit. Build. Eng.* **2014**, *13*, 445–451. [CrossRef]
29. Mukhopadhyay, S.; Khatana, S. A review on the use of fibers in reinforced cementitious concrete. *J. Ind. Text.* **2015**, *45*, 239–264. [CrossRef]
30. Danihelová, A.; Němec, M.; Gergeľ, T.; Gejdoš, M.; Gordanová, J.; Sčensný, P. Usage of Recycled Technical Textiles as Thermal Insulation and an Acoustic Absorber. *Sustainability* **2019**, *11*, 2968. [CrossRef]
31. Enache, F.; Vasile, V.; Gruin, A.; Bolborea, B. Use of wool in the composition of building materials-sustainable solution for improving thermal, acoustic performance and indoor air quality. *Constructii* **2020**, *21*, 43–46.
32. Jami, T.; Karade, S.R.; Singh, L.P. A review of the properties of hemp concrete for green building applications. *J. Clean. Prod.* **2019**, *239*, 117852. [CrossRef]
33. Pixabay GmbH. Available online: https://pixabay.com/ (accessed on 6 November 2022).
34. Next Technology Tecnotessile (NTT). Available online: https://www.tecnotex.it (accessed on 6 November 2022).
35. Kizildag, N. Smart composite nanofiber mats with thermal management functionality. *Sci. Rep.* **2021**, *11*, 4256. [CrossRef]
36. Chalco-Sandoval, W.; Fabra, M.J.; López-Rubio, A.; Lagaron, J.M. Use of phase change materials to develop electrospun coatings of interest in food packaging applications. *J. Food Eng.* **2017**, *192*, 122–128. [CrossRef]
37. Paroutoglou, E.; Fojan, P.; Gurevich, L.; Afshari, A. Thermal Properties of Novel Phase-Change Materials Based on Tamanu and Coconut Oil Encapsulated in Electrospun Fiber Matrices. *Sustainability* **2022**, *14*, 7432. [CrossRef]
38. Mao, X.; Hatton, T.A.; Rutledge, G.C. A Review of Electrospun Carbon Fibers as Electrode Materials for Energy Storage. *Curr. Org. Chem.* **2013**, *17*, 1390–1401. [CrossRef]
39. Ivanoska-Dacikj, A.; Stachewicz, U. Smart textiles and wearable technologies—Opportunities offered in the fight against pandemics in relation to current COVID-19 state. *Rev. Adv. Mater. Sci.* **2020**, *59*, 487–505. [CrossRef]
40. Metwally, S.; Comesaña, S.M.; Zarzyka, M.; Szewczyk, P.K.; Karbowniczek, J.E.; Stachewicz, U. Thermal insulation design bioinspired by microstructure study of penguin feather and polar bear hair. *Acta Biomater.* **2019**, *91*, 270–283. [CrossRef]
41. Altay, P.; Uçar, N. Comparative analysis of sound and thermal insulation properties of porous and non-porous polystyrene submicron fiber membranes. *J. Text. Inst.* **2022**, *113*, 2177–2184. [CrossRef]
42. Si, Y.; Yu, Y.; Tang, X.; Ge, J.; Ding, B. Ultralight nanofibre-assembled cellular aerogels with superelasticity and multifunctionality. *Nat. Commun.* **2014**, *5*, 5802. [CrossRef]
43. Bertocchi, M.J.; Vang, P.; Balow, R.B.; Wynne, J.H.; Lundin, J.G. Enhanced Mechanical Damping in Electrospun Polymer Fibers with Liquid Cores: Applications to Sound Damping. *ACS Appl. Polym. Mater.* **2019**, *1*, 2068–2076. [CrossRef]
44. Alves, J.; Paiva, F.; Silva, L.; Remoaldo, P. Low-Frequency Noise and Its Main Effects on Human Health—A Review of the Literature between 2016 and 2019. *Appl. Sci.* **2020**, *10*, 5205. [CrossRef]

45. Hurrell, A.; Horoshenkov, K.; King, S.; Stolojon, V. On the relationship of the observed acoustical and related non-acoustical behaviours of nanofibers membranes using Biot- and Darcy-type models. *Appl. Acoust.* **2021**, *179*, 108075. [CrossRef]
46. Rabbi, A.; Bahrambeygi, H.; Shoushtari, A.M.; Nasouri, K. Incorporation of Nanofiber Layers in Nonwoven Materials for Improving Their Acoustic Properties. *J. Eng. Fibers Fabr.* **2013**, *8*, 155892501300800412. [CrossRef]
47. Weschler, C.J. Ozone's Impact on Public Health: Contributions from Indoor Exposures to Ozone and Products of Ozone-Initiated Chemistry. *Environ. Health Perspect.* **2006**, *114*, 1489–1496. [CrossRef] [PubMed]
48. Lakey, P.S.J.; Morrison, G.C.; Won, Y.; Parry, K.M.; Von Domaros, M.; Tobias, D.J.; Rim, D.; Shiraiwa, M. The impact of clothing on ozone and squalene ozonolysis products in indoor environments. *Commun. Chem.* **2019**, *2*, 56. [CrossRef]
49. Abbass, O.A.; Sailor, D.J.; Gall, E.T. Effect of fiber material on ozone removal and carbonyl production from carpets. *Atmos. Environ.* **2017**, *148*, 42–48. [CrossRef]
50. Abidi, M.; Hajjaji, A.; Bouzaza, A.; Lamaa, L.; Peruchon, L.; Brochier, C.; Rtimi, S.; Wolbert, D.; Bessais, B.; Assadi, A.A. Mod-eling of indoor air treatment using an innovative photocatalytic luminous textile: Reactor compactness and mass transfer enhancement. *Chem. Eng. J.* **2022**, *430*, 132636. [CrossRef]
51. Zhu, L.; Liu, Y.; Ding, X.; Wu, X.; Sand, W.; Zhou, H. A novel method for textile odor removal using engineered water nanostructures. *RSC Adv.* **2019**, *9*, 17726–17736. [CrossRef]
52. Akinci, Z.S.; Marquet, O.; Delclòs-Alió, X.; Miralles-Guasch, C. Urban vitality and seniors' outdoor rest time in Barcelona. *J. Transp. Geogr.* **2022**, *98*, 103241. [CrossRef]
53. Chang, P.-J. Effects of the built and social features of urban greenways on the outdoor activity of older adults. *Landsc. Urban Plan.* **2020**, *204*, 103929. [CrossRef]
54. Larriva, M.T.B.; Higueras, E. Health risk for older adults in Madrid, by outdoor thermal and acoustic comfort. *Urban Clim.* **2020**, *34*, 100724. [CrossRef]
55. Yıldırım, M. Shading in the outdoor environments of climate-friendly hot and dry historical streets: The passageways of Sanliurfa, Turkey. *Environ. Impact Assess. Rev.* **2019**, *80*, 106318. [CrossRef]
56. Szopińska, E.; Kazak, J.; Kempa, O.; Rubaszek, J. Spatial Form of Greenery in Strategic Environmental Management in the Context of Urban Adaptation to Climate Change. *Pol. J. Environ. Stud.* **2019**, *28*, 2845–2856. [CrossRef]
57. Adams, G.R.; Okoli, O.I. A review of perovskite solar cells with a focus on wire-shaped devices. *Renew. Energy Focus* **2018**, *25*, 17–23. [CrossRef]
58. Hussain, I.; Chowdhury, A.R.; Jaksik, J.; Grissom, G.; Touhami, A.; Ibrahim, E.E.; Schauer, M.; Okoli, O.; Uddin, M.J. Conductive glass free carbon nanotube micro yarn based perovskite solar cells. *Appl. Surf. Sci.* **2019**, *478*, 327–333. [CrossRef]
59. Yang, Y.; Hoang, M.T.; Bhardwaj, A.; Wilhelm, M.; Mathur, S.; Wang, H. Perovskite solar cells based self-charging power packs: Fundamentals, applications and challenges. *Nano Energy* **2022**, *94*, 106910. [CrossRef]
60. Zhang, X.; Shiu, B.; Li, T.-T.; Liu, X.; Ren, H.-T.; Wang, Y.; Lou, C.-W.; Lin, J.-H. Photo-thermoelectric nanofiber film based on the synergy of conjugated polymer and light traps for the solar-energy harvesting of textile solar panel. *Sol. Energy Mater. Sol. Cells* **2021**, *232*, 111353. [CrossRef]
61. Zhang, X.; Shiu, B.; Li, T.-T.; Liu, X.; Ren, H.-T.; Wang, Y.; Lou, C.-W.; Lin, J.-H. Synergistic work of photo-thermoelectric and hydroelectric effects of hierarchical structure photo-thermoelectric textile for solar energy harvesting and solar steam generation simultaneously. *Chem. Eng. J.* **2021**, *426*, 131923. [CrossRef]
62. Zhou, Y.; Chen, Y.; Zhang, Q.; Zhou, Y.; Tai, M.; Koumoto, K.; Lin, H. A highly-efficient concentrated perovskite solar cell-thermoelectric generator tandem system. *J. Energy Chem.* **2021**, *59*, 730–735. [CrossRef]
63. Du, K.; Lin, R.; Yin, L.; Ho, J.S.; Wang, J.; Lim, C.T. Electronic textiles for energy, sensing, and communication. *iScience* **2022**, *25*, 104174. [CrossRef]
64. Liu, J.; Wei, Y.; Lu, S.; Wang, R.; Chen, L.; Xu, F. The elderly's preference for the outdoor environment in Fragrant Hills Nursing Home, Beijing: Interpreting the visual-behavioural relationship. *Urban For. Urban Green.* **2021**, *64*, 127242. [CrossRef]
65. Arcelus, A.; Jones, M.H.; Goubran, R.; Knoefel, F. Integration of Smart Home Technologies in a Health Monitoring System for the Elderly. In Proceedings of the 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07), Niagara Falls, ON, Canada, 21–23 May 2007.
66. Karagoz, S.; Kiremitler, N.B.; Sarp, G.; Pekdemir, S.; Salem, S.; Goksu, A.G.; Onses, M.S.; Sozdutmaz, I.; Sahmetlioglu, E.; Ozkara, E.S.; et al. Antibacterial, Antiviral, and Self-Cleaning Mats with Sensing Capabilities Based on Electrospun Nanofibers Decorated with ZnO Nanorods and Ag Nanoparticles for Protective Clothing Applications. *ACS Appl. Mater. Interfaces* **2021**, *13*, 5678–5690. [CrossRef]
67. Goel, S.; Hawi, S.; Goel, G.; Thakur, V.K.; Agrawal, A.; Hoskins, C.; Pearce, O.; Hussain, T.; Upadhyaya, H.M.; Cross, G.; et al. Resilient and agile engineering solutions to address societal challenges such as coronavirus pandemic. *Mater. Today Chem.* **2020**, *17*, 100300. [CrossRef]
68. Naragund, V.S.; Panda, P.K. Electrospun nanofiber-based respiratory face masks—A review. *Emergent Mater.* **2022**, *5*, 261–278. [CrossRef] [PubMed]
69. Zakrzewska, A.; Bayan, M.A.H.; Nakielski, P.; Petronella, F.; De Sio, L.; Pierini, F. Nanotechnology Transition Roadmap toward Multifunctional Stimuli-Responsive Face Masks. *ACS Appl. Mater. Interfaces* **2022**, *14*, 46123–46144. [CrossRef] [PubMed]
70. Wang, Y.; Tan, P.; Wu, Y.; Luo, D.; Li, Z. Artificial intelligence-enhanced skin-like sensors based on flexible nanogenerators. *View* **2022**, *3*, 20220026. [CrossRef]

71. Babu, A.; Aazem, I.; Walden, R.; Bairagi, S.; Mulvihill, D.M.; Pillai, S.C. Electrospun nanofiber based TENGs for wearable electronics and self-powered sensing. *Chem. Eng. J.* **2022**, *452*, 139060. [CrossRef]
72. Pang, Y.; Cao, Y.; Derakhshani, M.; Fang, Y.; Wang, Z.L.; Cao, C. Hybrid Energy-Harvesting Systems Based on Triboelectric Nanogenerators. *Matter* **2021**, *4*, 116–143. [CrossRef]
73. Busolo, T.; Szewczyk, P.K.; Nair, M.; Stachewicz, U.; Kar-Narayan, S. Triboelectric Yarns with Electrospun Functional Polymer Coatings for Highly Durable and Washable Smart Textile Applications. *ACS Appl. Mater. Interfaces* **2021**, *13*, 16876–16886. [CrossRef] [PubMed]
74. Ura, D.P.; Stachewicz, U. The Significance of Electrical Polarity in Electrospinning: A Nanoscale Approach for the Enhancement of the Polymer Fibers' Properties. *Macromol. Mater. Eng.* **2022**, *307*, 2100843. [CrossRef]
75. Stachewicz, U.; Dijksman, J.F.; Yurteri, C.; Marijnissen, J.C.M. Experiments on single event electrospraying. *Appl. Phys. Lett.* **2007**, *91*, 254109. [CrossRef]
76. Stachewicz, U.; Stone, C.A.; Willis, C.R.; Barber, A.H. Charge assisted tailoring of chemical functionality at electrospun nanofiber surfaces. *J. Mater. Chem.* **2012**, *22*, 22935–22941. [CrossRef]
77. Szewczyk, P.K.; Stachewicz, U. The impact of relative humidity on electrospun polymer fibers: From structural changes to fiber morphology. *Adv. Colloid Interface Sci.* **2020**, *286*, 102315. [CrossRef]
78. Stachewicz, U.; Modaresifar, F.; Bailey, R.J.; Peijs, T.; Barber, A.H. Manufacture of Void-Free Electrospun Polymer Nanofiber Composites with Optimized Mechanical Properties. *ACS Appl. Mater. Interfaces* **2012**, *4*, 2577–2582. [CrossRef] [PubMed]
79. Ura, D.P.; Rosell-Llompart, J.; Zaszczyńska, A.; Vasilyev, G.; Gradys, A.; Szewczyk, P.K.; Knapczyk-Korczak, J.; Avrahami, R.; Šišková, A.O.; Arinstein, A.; et al. The Role of Electrical Polarity in Electrospinning and on the Mechanical and Structural Properties of As-Spun Fibers. *Materials* **2020**, *13*, 4169. [CrossRef] [PubMed]
80. Mailley, D.; Hébraud, A.; Schlatter, G. A Review on the Impact of Humidity during Electrospinning: From the Nanofiber Structure Engineering to the Applications. *Macromol. Mater. Eng.* **2021**, *306*, 2100115. [CrossRef]
81. Xue, J.; Wu, T.; Dai, Y.; Xia, Y. Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications. *Chem. Rev.* **2019**, *119*, 5298–5415. [CrossRef]
82. Lavielle, N.; Hébraud, A.; Schlatter, G.; Thöny-Meyer, L.; Rossi, R.M.; Popa, A.M. Simultaneous Electrospinning and Electrospraying: A Straightforward Approach for Fabricating Hierarchically Structured Composite Membranes. *ACS Appl. Mater. Interfaces* **2013**, *5*, 10090–10097. [CrossRef]
83. Stachewicz, U.; Qiao, T.; Rawlinson, S.C.; Almeida, F.; Li, W.-Q.; Cattell, M.; Barber, A.H. 3D imaging of cell interactions with electrospun PLGA nanofiber membranes for bone regeneration. *Acta Biomater.* **2015**, *27*, 88–100. [CrossRef]
84. Krysiak, Z.J.; Stachewicz, U. Electrospun fibers as carriers for topical drug delivery and release in skin bandages and patches for atopic dermatitis treatment. *WIREs Nanomed. Nanobiotechnol.* **2022**, e1829. [CrossRef]
85. Jun, I.; Han, H.-S.; Edwards, J.R.; Jeon, H. Electrospun Fibrous Scaffolds for Tissue Engineering: Viewpoints on Architecture and Fabrication. *Int. J. Mol. Sci.* **2018**, *19*, 745. [CrossRef]
86. Martins, A.; Reis, R.L.; Neves, N.M. Electrospinning: Processing technique for tissue engineering scaffolding. *Int. Mater. Rev.* **2008**, *53*, 257–274. [CrossRef]
87. Knapczyk-Korczak, J.; Szewczyk, P.K.; Stachewicz, U. The importance of nanofiber hydrophobicity for effective fog water collection. *RSC Adv.* **2021**, *11*, 10866–10873. [CrossRef]
88. Knapczyk-Korczak, J.; Stachewicz, U. Biomimicking spider webs for effective fog water harvesting with electrospun polymer fibers. *Nanoscale* **2021**, *13*, 16034–16051. [CrossRef] [PubMed]
89. Ura, D.P.; Knapczyk-Korczak, J.; Szewczyk, P.K.; Sroczyk, E.A.; Busolo, T.; Marzec, M.M.; Bernasik, A.; Kar-Narayan, S.; Stachewicz, U. Surface Potential Driven Water Harvesting from Fog. *ACS Nano* **2021**, *15*, 8848–8859. [CrossRef] [PubMed]
90. Knapczyk-Korczak, J.; Szewczyk, P.K.; Ura, D.P.; Berent, K.; Stachewicz, U. Hydrophilic nanofibers in fog collectors for increased water harvesting efficiency. *RSC Adv.* **2020**, *10*, 22335–22342. [CrossRef] [PubMed]
91. Szewczyk, P.K.; Gradys, A.; Kim, S.K.; Persano, L.; Marzec, M.; Kryshtal, A.; Busolo, T.; Toncelli, A.; Pisignano, D.; Bernasik, A.; et al. Enhanced Piezoelectricity of Electrospun Polyvinylidene Fluoride Fibers for Energy Harvesting. *ACS Appl. Mater. Interfaces* **2020**, *12*, 13575–13583. [CrossRef]
92. Busolo, T.; Ura, D.P.; Kim, S.K.; Marzec, M.M.; Bernasik, A.; Stachewicz, U.; Kar-Narayan, S. Surface potential tailoring of PMMA fibers by electrospinning for enhanced triboelectric performance. *Nano Energy* **2018**, *57*, 500–506. [CrossRef]
93. Karbowniczek, J.E.; Ura, D.P.; Stachewicz, U. Nanoparticles distribution and agglomeration analysis in electrospun fiber based composites for desired mechanical performance of poly(3-hydroxybuty-rate-co-3-hydroxyvalerate (PHBV) scaffolds with hydroxyapatite (HA) and titanium dioxide (TiO_2) towards medical applications. *Compos. Part B Eng.* **2022**, *241*, 110011. [CrossRef]
94. Kaniuk, Ł.; Podborska, A.; Stachewicz, U. Enhanced mechanical performance and wettability of PHBV fiber blends with evening primrose oil for skin patches improving hydration and comfort. *J. Mater. Chem. B* **2022**, *10*, 1763–1774. [CrossRef]
95. Hong, K. SMART Textiles: The Use of Embedded Technology on Tactile Textiles as Therapy for the Elderly. In *Proceedings of the International Colloquium in Textile Engineering, Fashion, Apparel and Design 2014 (ICTEFAD 2014)*; Ahmad, M., Yahya, M., Eds.; Springer: Singapore, 2014; pp. 43–47. [CrossRef]
96. Patel, S.; Park, H.; Bonato, P.; Chan, L.; Rodgers, M. A review of wearable sensors and systems with application in rehabilitation. *J. Neuroeng. Rehabil.* **2012**, *9*, 21. [CrossRef]

97. Jakob, A.; Collier, L. Sensory enrichment for people living with dementia: Increasing the benefits of multisensory environments in dementia care through design. *Des. Health* **2017**, *1*, 115–133. [CrossRef]
98. Treadaway, C.; Fennell, J.; Kenning, G.; Prytherch, D.; Walters, A. Designing for wellbeing in late stage dementia, Well-Being 2016: Co-Creating Pathways to Well-Being. In Proceedings of the Third International Conference Exploring the Multi-Dimensions of Well-Being, Birmingham, UK, 5–6 September 2016; pp. 126–129.
99. Yang, K.; Isaia, B.; Brown, L.J.; Beeby, S. E-Textiles for Healthy Ageing. *Sensors* **2019**, *19*, 4463. [CrossRef]