engineering proceedings

Proceeding Paper

Advancements in Textile Roofing Solutions for Challenging Weather Conditions †

Kim-Laura Moselewski [1], Emilia Wirth [2] and Lilia Sabantina [3,4,*]

[1] Faculty of Textile and Clothing Technology, Niederrhein University of Applied Sciences, 41065 Moenchengladbach, Germany; kim.moselewski@icloud.com
[2] Independent Researcher, 50733 Cologne, Germany; emiliawirth@gmx.de
[3] Faculty of Apparel Engineering and Textile Processing, Berlin School of Culture + Design, Berlin University of Applied Sciences—HTW Berlin, 12459 Berlin, Germany
[4] Department of Textile and Paper Engineering, Polytechnic University of Valencia, 03801 Alcoy, Spain
* Correspondence: lilia.sabantina@htw-berlin.de
† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.

Abstract: This review explores the progress and significance of textile roofing solutions in withstanding challenging weather conditions. Specially treated fabrics are designed to withstand a variety of climatic challenges, including heavy rainfall, extreme heat, and strong winds. The focus is on the application of these innovative roofing systems in various environments to enhance comfort and safety for individuals exposed to harsh weather. Additionally, it investigates the use of durable and weather-resistant materials and discusses the technological advancements in the design and manufacturing of these advanced textile products. The review provides insights into the continuous evolution of textile roofing technologies, improving shelter and protection in extreme climates. It also explores areas of innovation in textile roofing, encompassing the adoption of textile membranes, the incorporation of fibers and textiles into roof constructions, the latest advancements in textile materials, and a wide range of roofing applications, and provides an overview of companies offering materials and technologies for textile roofing solutions.

Keywords: textile roofing solutions; textiles; fibers; weather-resistant materials; textile-reinforced solutions

check for updates

Citation: Moselewski, K.-L.; Wirth, E.; Sabantina, L. Advancements in Textile Roofing Solutions for Challenging Weather Conditions. *Eng. Proc.* **2023**, *56*, 292. https://doi.org/10.3390/ASEC2023-15974

Academic Editor: Manoj Gupta

Published: 14 November 2023

1. Introduction

Textile roofing solutions have proven to be a promising innovation, providing protection and safety for people and withstanding difficult climatic conditions [1,2]. Specially treated textiles and fabrics are increasingly being used to meet the challenges posed by heavy rainfall, extreme heat, or high winds in different climatic environments [3,4]. The requirements for textile roofs are many and varied. They must have exceptional weather resistance to protect against rain, hail, snow, and UV radiation. In addition, high tensile strength and durability are essential to withstand wind forces and any potential mechanical loads. Excellent thermal insulation is also critical to maintaining a comfortable indoor environment, especially in regions with extreme temperatures. The materials used should also be fire resistant and non-combustible to ensure safety. They should also be lightweight so that they reduce structural loads while still being capable of handling snow. UV stability is critical to prevent material degradation over time. In addition to these technical considerations, aesthetic aspects can be important, as textile roofs can contribute to the overall architectural design and visual appeal of a structure. Textile roofing solutions need to balance these requirements and demonstrate a fusion of functionality, durability, safety, and aesthetic coherence, all while adapting to different climatic challenges.

While many scientific papers have examined the effects of green roofs, there are a limited number of resources that address textile membrane roofs and the materials used.

The available literature on this specific topic is relatively scarce. This suggests that further research is needed to improve the understanding of textile membrane roofs and their material properties. This review will focus on recent advances in the application and development of textile roofing solutions and will provide an overview of applications already available in the marketplace.

2. Textile Membranes

The indoor environment and energy dynamics of buildings are greatly influenced by the optical characteristics of the textile membrane material used in roofing. These membrane materials must meet several challenges, such as managing heat transfer both from the environment into the building and vice versa, including radiation and convection due to solar radiation and external weather conditions. Heat conduction within the membrane itself can be neglected. Typically, scientific literature provides limited coverage of textile membrane constructions, with the majority of literature reviews focusing on office buildings, green roofs, or the materials used [5–8]. When the term "membranes" is used, it refers to textile membranes with fibers and fabrics, excluding foils [9].

Although a few buildings with multi-layer membrane roofs have been constructed in recent years, there is a lack of publicly available information about them. The study by Gürlich et al. investigates the use of daylight in buildings to improve visual comfort and energy efficiency. A special textile membrane was used as a roof to harness daylight and reduce heating requirements. The results show that this roof construction can reduce the electricity required for lighting by 30% and provides valuable insights for similar building designs in the future [10]. The study by Reimann et al. developed a simulation model for multi-layer membrane roofs. Its purpose is to quickly estimate the annual energy demand of a membrane-based building under realistic weather scenarios [11]. Membrane materials vary and can be changed to meet design requirements [12]. They have different physical and aesthetic properties for reuse [13]. Composed of different materials and layers, textile membranes offer different weights, densities, and strengths as needed. After their use as a roofing material, textile membranes need to be recycled, with several considerations [14–16]. Morandi and Monticelli demonstrate a method for recycling textile membranes for subsequent acoustic applications in buildings [17]. These properties have a significant impact on acoustic performance, particularly sound absorption. A higher sound absorption index improves reverberation time reduction. Material density and porosity determine the sound absorption coefficient. The construction sector contributes significantly to the energy and material consumption throughout the life cycle of a building. In their study, Antolinc and Eleršič Filipič explore the use of industrial nonwoven textile waste for the production of thermal and acoustic panels. They convert polyester nonwoven textiles, obtained as strips and bales from the production line, into compact thermal insulation boards by shredding them into smaller segments and then compressing them using a hot press [18].

3. Use of Fibers and Textiles in Roof Constructions

Textile roofing solutions are used in a wide range of environments exposed to extreme weather conditions, and some developments in this field are explained in some studies where fibers and textiles are applied [19,20]. A few specifically discuss the use of fibers and textiles in building construction. Orlowsky et al. conducted a study on textile-reinforced concrete in construction and building maintenance [21]. The study conducted by Ngo and Nguyen included experimental and numerical analyses of bolted joints in thin-walled textile-reinforced concrete (TRC) panels. The research investigated the performance of connections in TRC structures and identified the potential of the open-box panel design for applications in walls, floors, and roofs [22]. Exploring the concept of function-integrated design, Su et al. introduced a novel sandwich roof panel made of basalt fiber-reinforced plastic (BFRP) material. The study involves a comprehensive approach that includes experiments, theoretical investigations, and numerical analyses to evaluate the thermal properties of these innovative roof panels [23]. In the work of Islam et al., a comparative analysis was performed to investigate carbon fiber and galvanized iron textile-reinforced concrete [24]. The research by Khan et al. provided an overview of the various properties of textile-reinforced concrete [25].

4. Current Textile Material Developments

The selection of appropriate materials and manufacturing technologies is key to the success of textile roofing solutions. Specially treated textile fibers and fabrics offer high weather resistance and robustness. These materials undergo a sophisticated process that increases their resistance to extreme weather conditions [26]. In addition, technological advances in the textile industry allow the development of high-quality materials with improved properties such as UV stability, wind load, flexibility, color fastness, and fire safety [27–30]. A roof waterproofing system that combines a water-based polymer membrane with infrared reflective additives to ensure thermal reflectivity is reported in the study by Ferreira et al. A smart textile substrate reinforces the membrane and contains moisture and temperature sensors. Tests confirm the high solar reflectivity of the membrane, the robustness of the textile substrate, and the successful integration of the sensors. The developed solution shows potential for roof optimization in different climates and is competitive in climate change and adaptation solutions, especially in sunny areas [31].

Liu et al. analyzed the application and suitability of energy efficiency measures (EEMs) and renewable energy technologies (RETs) in near-zero energy buildings (NZEBs) in China. The study focused on minimizing energy demand through EEMs, such as efficient insulation and windows, and introducing RETs, such as solar PV/T, air, and ground [32]. Qiao et al. explored a novel heat resistant structural system incorporating a cementitious honeycomb composite (HSCC) for efficient heat dissipation. The active heat dissipation enabled by the HSCC outperformed passive insulation in improving thermal resistance under pressure. The study used microscopic thermal imaging and finite element simulation to analyze the heat transfer processes of the 3D-printed microscaffold-based HSCC. With a conductivity of 0.24 W/mK, the proposed material showed a 30% improvement in thermal resistance compared to lightweight concrete. The innovative support system combined ventilation through the HSCC with its low thermal conductivity, resulting in loss of a thermal capacity at 1300 °C that was much lower than that of conventional concrete walls [33]. Hussein et al. focused on improving the seam quality and peel strength of multilayer hybrid textiles through continuous ultrasonic welding, demonstrating its advantages for weatherproofing applications and promoting bonding techniques [34]. Li and Zanelli presented a comprehensive review of textile-envelope integrated flexible photovoltaic (TE-FPV) systems, covering both their fabrication processes and the wide range of applications they encompass. [35]. The study by Parankar et al. presented a technique for the preparation of chitosan-based finishes that impart flame-retardant, UV-protective, and antibacterial properties to cotton fabrics. The method involves the synthesis of nitrogen- and phosphorus-rich green multifunctional chemicals to achieve these functional enhancements in the cotton fabrics [36]. The thermal analysis of enclosed domes with double-layer PTFE fabric roofs integrated with aerogel-glass wool insulation mats was discussed by Yin et al. The study included on-site testing of the thermal environment in a sports dome with this roof configuration [37]. Hu et al. Investigated the long-term thermal performance of enclosed, large-span swimming stadiums with retractable membrane roofs. The study focused on aspects such as structural behavior, serviceability, and energy requirements that collectively influenced the performance of the building [38].

5. Textile Roofing Applications

Textile roofing solutions are used in a wide range of environments [39–42]. From urban environments with heavy rainfall and thunderstorms to desert regions with searing heat and sandstorms, these textile roofs must provide effective protection. Their adaptability is especially valuable in areas with seasonal climate fluctuations, such as deserts that experience cold and stormy conditions in winter. Notable research efforts have addressed this issue. For example, Zhu and Feng's study highlighted advances in textile materials for personal radiant heat management in both indoor and outdoor environments [43]. Sproul et al. conducted an economic comparison of white, green, and black flat roofs and concluded that white roofs have a 3-fold advantage over green roofs in terms of mitigating global warming [44]. Given that humans spend approximately 90% of their time indoors, it is increasingly important to consider the environmental impact of daily indoor activities, including homes, workplaces, and commercial spaces [45].

As the demand for effective roofing solutions grows, several companies have already introduced their offerings to the market. Table 1 provides an overview of the various applications in which textile roofing solutions have been implemented. The variety of environments in which these textile solutions are being used demonstrates their versatility and potential.

Table 1. An overview of the companies offering materials and technologies for textile roofing solutions.

Companies	Materials and Technologies	References
Geiger Engineers	Enduring structural fabric and membrane materials encompass TEFLON™-coated fiberglass® and other types of membranes.	[46]
Birdair Inc.	Tensotherm™ composite consists of a thin, translucent membrane integrated into aerogel, which is enclosed between an outer skin made of a PTFE- or PVC-coated factory membrane and a thinner, lighter inner layer serving as an acoustic or vapor barrier (U.S. Patent No. 8,899,0009).	[47,48]
Vector Folitec GmbH	The Texlon® system employs pneumatically stabilized film components that are fused through welding. Typically, these components consist of either two or five layers of ETFE film (ethylene tetrafluoroethylene). The thickness of the ETFE film ranges from 80 µm to 300 µm, based on the structural needs of the building.	[49]
Serge Ferrari Group	Flexlight Xtrem TX30-II utilizes crosslink technology to create a high-performance membrane. During the production process, the polyester microcable is stretched bidirectionally while being coated.	[50]
Temme Obermeier GmbH	Tailored materials and customized membrane configurations encompass PES/PVC, ETFE, PTFE, Silicone/Glass, and Low-E coatings.	[51]
3dtex GmbH	3d-IsoSkin represents a multi-layered system containing insulating material, wherein various fabric layers can be integrated in combination.	[52]

6. Conclusions and Future Outlook

Textile roofing solutions face challenges that must be overcome to ensure optimal performance. The need to withstand extreme weather conditions requires continuous research and development to further improve the performance of textile roofing systems. Further research into the durability and longevity of textile materials during prolonged exposure to harsh climatic conditions is critical. In addition, the integration of smart and responsive textiles that can adapt to changing weather patterns holds great promise. Collaboration between architects, engineers, and material scientists is likely to lead to more innovative and effective solutions for textile roofing. The use of specially treated fabrics combined with advanced manufacturing technologies has greatly improved the durability and performance of textile roofing systems in extreme climates. Despite these advances, there are still challenges to be overcome in the field of textile roofing, such as protecting the environment and improving the sustainability of textile roofing solutions. Future research and development in this area is needed to further improve the efficiency and functionality of textile roofing solutions to increase protection and safety in harsh weather conditions.

Author Contributions: Conceptualization, K.-L.M., E.W. and L.S.; methodology, E.W. and L.S.; validation, E.W. and L.S.; writing—original draft preparation, K.-L.M., E.W. and L.S.; writing—review and editing, K.-L.M., E.W. and L.S.; visualization, E.W. and L.S.; supervision, L.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Mishra, R.; Petru, M. 14—Application of knitted fabrics in textile structural composites. In *The Textile Institute Book Series, Advanced Knitting Technology*; Maity, S., Rana, S., Pandit, P., Singha, K., Eds.; Woodhead Publishing: Sawston, UK, 2022; pp. 411–470. [CrossRef]
2. Maity, S.; Singha, K.; Pandit, P. 1—Introduction to functional and technical textiles. In *The Textile Institute Book Series, Functional and Technical Textiles*; Maity, S., Singha, K., Pandit, P., Eds.; Woodhead Publishing: Sawston, UK, 2023; pp. 1–30. [CrossRef]
3. Sonnendecker, A.; Viljoen, D.; Ameduri, B.; Crouse, P. Chapter 10—Fluoropolymer-based architectural textiles: Production, processing, and characterization. In *Progress in Fluorine Science, Fascinating Fluoropolymers and Their Applications*; Ameduri, B., Fomin, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 337–399. [CrossRef]
4. Cassar, J.; Galdies, C.; Muscat Azzopardi, E. A New Approach to Studying Traditional Roof Behaviour in a Changing Climate—A Case Study from the Mediterranean Island of Malta. *Heritage* **2021**, *4*, 3543–3571. [CrossRef]
5. Rizzo, G.; Cirrincione, L.; La Gennusa, M.; Peri, G.; Scaccianoce, G. Green Roofs' End of Life: A Literature Review. *Energies* **2023**, *16*, 596. [CrossRef]
6. Yıldırım, S.; Özburak, Ç.; Özden, Ö. Green Roofs, Vegetation Types, Impact on the Thermal Effectiveness: An Experimental Study in Cyprus. *Sustainability* **2023**, *15*, 2807. [CrossRef]
7. Kazemi, M.; Rahif, R.; Courard, L.; Attia, S. Sensitivity analysis and weather condition effects on hygrothermal performance of green roof models characterized by recycled and artificial materials' properties. *Build. Environ.* **2023**, *237*, 110327. [CrossRef]
8. Rezende Leite, F.; Pereira Antunes, M.L. Green roof recent designs to runoff control: A review of building materials and plant species used in studies. *Ecol. Eng.* **2023**, *189*, 106924. [CrossRef]
9. Cremers, J.; Palla, N.; Buck, D.; Beck, A.; Biesinger, A.; Brodkorb, S. Analysis of a Translucent Insulated Triple-layer Membrane Roof for a Sport Centre in Germany. *Procedia Eng.* **2016**, *155*, 38–46. [CrossRef]
10. Gürlich, D.; Reber, A.; Biesinger, A.; Eicker, U. Daylight Performance of a Translucent Textile Membrane Roof with Thermal Insulation. *Buildings* **2018**, *8*, 118. [CrossRef]
11. Reimann, K.; Kneer, A.; Weißhuhn, C.; Blum, R.A.; Simulation model for the yearly energy demand of buildings with two-or-more -layered textile roofs. International Conference on Textile Composites and Inflatable Structures. In Structural Membranes; Oñate, E., Kröplin, B., Bletzinger, K.-U., Eds.; 2011. Available online: https://upcommons.upc.edu/bitstream/handle/2117/186081/MEMBRANES_2011-30_A%20simulation%20model%20for%20the%20yearly.pdf?sequence=1&isAllowed=y (accessed on 12 June 2023).
12. Sluyts, Y.; Glorieux, C.; Rychtarikova, M. Effective absorption of architectural ETFE mem-branes in the lab. In Proceedings of the Euroregio/BNAM 2022 Conference, Aalborg, Denmark, 9–11 May 2022; pp. 289–295. Available online: https://www.conforg.fr/erbnam2022/output_directory/data/articles/000005.pdf (accessed on 1 June 2023).
13. Chang, Y.; Liu, F. Review of Waterproof Breathable Membranes: Preparation, Performance and Applications in the Textile Field. *Materials* **2023**, *16*, 5339. [CrossRef] [PubMed]
14. Łuczak, B.; Sumelka, W.; Wypych, A. Experimental Analysis of Mechanical Anisotropy of Selected Roofing Felts. *Materials* **2021**, *14*, 6907. [CrossRef]
15. De Vita, M.; Beccarelli, P.; Laurini, E.; De Berardinis, P. Performance Analyses of Temporary Membrane Structures: Energy Saving and CO2 Reduction through Dynamic Simulations of Textile Envelopes. *Sustainability* **2018**, *10*, 2548. [CrossRef]
16. Czarnecki, S.; Rudner, M. Recycling of Materials from Renovation and Demolition of Building Structures in the Spirit of Sustainable Material Engineering. *Buildings* **2023**, *13*, 1842. [CrossRef]
17. Morandi, A.; Monticelli, C. Textile Membranes Reused as a Tool for Noise Control. *Buildings* **2023**, *13*, 2134. [CrossRef]
18. 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]
19. Chakartnarodom, P.; Prakaypan, W.; Ineure, P.; Chuankrerkkul, N.; Laitila, E.A.; Kongkajun, N. Properties and performance of the basalt-fiber reinforced texture roof tiles. *Case Stud. Constr. Mater.* **2020**, *13*, e00444. [CrossRef]

20. Halvaei, M. 3—Fibers and textiles reinforced cementitious composites. In *The Textile Institute Book Series, Engineered Polymeric Fibrous Materials*; Latifi, M., Ed.; Woodhead Publishing: Sawston, UK, 2021; pp. 73–92. [CrossRef]
21. Orlowsky, J.; Beßling, M.; Kryzhanovskyi, V. Prospects for the Use of Tex-tile-Reinforced Concrete in Buildings and Structures Maintenance. *Buildings* **2023**, *13*, 189. [CrossRef]
22. Ngo, D.Q.; Nguyen, H.C. Experimental and numerical investigations of textile-reinforced concrete thin-wall panel bolted connections. *Case Stud. Constr. Mater.* **2023**, *19*, e02229. [CrossRef]
23. Su, B.; Zhang, T.; Chen, S.; Hao, J.; Zhang, R. Thermal proper-ties of novel sandwich roof panel made of basalt fiber reinforced plastic material. *J. Build. Eng.* **2022**, *52*, 104478. [CrossRef]
24. Islam, M.J.; Ahmed, T.; Imam, S.M.F.B.; Islam, H.; Shaikh, F.U.A. Comparative study of carbon fiber and galvanized iron textile reinforced concrete. *Constr. Build. Mater.* **2023**, *374*, 130928. [CrossRef]
25. Khan, M.B.; Waqar, A.; Bheel, N.; Shafiq, N.; Hamah Sor, N.; Radu, D.; Benjeddou, O. Optimization of Fresh and Mechanical Characteristics of Carbon Fiber-Reinforced Concrete Composites Using Response Surface Technique. *Buildings* **2023**, *13*, 852. [CrossRef]
26. Silva, A.C.Q.; Silvestre, A.J.D.; Freire, C.S.R.; Vilela, C. 10—Modification of textiles for functional applications. In *The Textile Institute Book Series, Fundamentals of Natural Fibres and Textiles*; Mondal, I.H., Ed.; Woodhead Publishing: Sawston, UK, 2021; pp. 303–365. [CrossRef]
27. Pereira, C.; Pereira, A.M.; Freire, C.; Pinto, T.V.; Costa, R.S.; Teixeira, J.S. Chapter 21—Nanoengineered textiles: From advanced functional nanomaterials to ground-breaking high-performance clothing. In *Micro and Nano Technologies, Handbook of Functionalized Nanomaterials for Industrial Applications*; Hussain, C.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 611–714. [CrossRef]
28. Pervez, M.N.; Hossain, M.Y.; Talukder, M.E.; Faisal, A.M.; Hasan, K.M.F.; Islam, M.; Ahmed, F.; Cai, Y.; Stylios, G.K.; Naddeo, V.; et al. 3—Nanomaterial-based smart and sustainable protective textiles. In *The Textile Institute Book Series, Protective Textiles from Natural Resources*; Mondal, I.H., Ed.; Woodhead Publishing: Sawston, UK, 2022; pp. 75–111. [CrossRef]
29. Nguyen, K.T.Q.; Navaratnam, S.; Mendis, P.; Zhang, K.; Barnett, J.; Wang, H. Fire safety of composites in prefabricated buildings: From fibre reinforced polymer to textile reinforced concrete. *Compos. Part B Engineering* **2020**, *187*, 107815. [CrossRef]
30. Li, M.; Wang, F.P.; Boussu, F.; Soulat, D. Investigation of impact performance of 3-dimensional interlock polymer fabrics in double and multi-angle pass stabbing. *Mater. Des.* **2021**, *206*, 109775. [CrossRef]
31. Ferreira, C.; Ribeiro, J.; Furtado, C.; Salazar, C.; Sá, I.; Silva, R.; Midão, M.; Silva, L.; Sequeira, P.; Ferreira, P.; et al. Smart Roofs System: Moisture and Temperature Monitoring on Smart Roofs. In *Sustainable, Innovative and Intelligent Societies and Cities. EAI/Springer Innovations in Communication and Computing*; da Silva Portela, C.F., Ed.; Springer: Cham, Switzerland, 2023; Volume 14, pp. 329–354. [CrossRef]
32. Liu, Z.; Liu, Y.; He, B.J.; Xu, W.; Jin, G.; Zhang, X. Application and sustainability analysis of the key technologies in nearly zero energy buildings in China. *Renew. Sustain. Energy Rev.* **2019**, *101*, 329–345. [CrossRef]
33. Qiao, Y.; Ren, J.; Wu, J.; Chen, S.J. A new heat resistant load bearing system incorporating honeycomb structured cementitious composite investigated via experiments and modelling. *Case Stud. Constr. Mater.* **2023**, *19*, e02379. [CrossRef]
34. Hussen, M.S.; Kyosev, Y.; Pietsch, K.; Pilling, T.; Boll, J.; Kabish, A.K. Uncovering the peel strength performance of multi-layer ultrasonic weld seams in PVC-coated hybrid textiles for weather protection. *J. Adv. Join. Process.* **2023**, *8*, 100151. [CrossRef]
35. Li, Q.; Zanelli, A. A review on fabrication and applications of textile envelope integrated flexible photovoltaic systems. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110678. [CrossRef]
36. Patankar, K.C.; Biranje, S.; Pawar, A.; Maiti, S.; Shahid, M.; More, S.; Adivarekar, R.V. Fabrication of chitosan-based finishing agent for flame-retardant, UV-protective, and antibacterial cotton fabrics. *Mater. Today Commun.* **2022**, *33*, 104637. [CrossRef]
37. Yin, Y.; Song, Y.; Chen, W.; Yan, Y.; Wang, X.; Hu, J.; Zhao, B.; Ren, S. Thermal environment analysis of enclosed dome with double-layered PTFE fabric roof integrated with aerogel-glass wool insulation mats: On-site test and numerical simulation. *Energy Build.* **2022**, *254*, 111621. [CrossRef]
38. Hu, J.; Kawaguchi, K.; Ma, J. Long-term building thermal performance of enclosed large-span swimming stadiums with retractable membrane ceilings. *Energy Build.* **2020**, *207*, 109363. [CrossRef]
39. Kalthoff, M.; Bosbach, S.; Backes, J.G.; Morales Cruz, C.; Claßen, M.; Traverso, M.; Raupach, M.; Matschei, T. Fabrication of lightweight, carbon textile reinforced concrete components with internally nested lattice structure using 2-layer extrusion by LabMorTex. *Constr. Build. Mater.* **2023**, *395*, 132334. [CrossRef]
40. Mastrapostoli, E.; Karlessi, T.; Pantazaras, A.; Kolokotsa, D.; Gobakis, K.; Santamouris, M. On the cooling potential of cool roofs in cold climates: Use of cool fluorocar-bon coatings to enhance the optical properties and the energy performance of industrial buildings. *Energy Build.* **2014**, *69*, 417–425. [CrossRef]
41. Alimohammad, S.; Mohammad, S. Mitigation of the impacts of heat islands on energy consumption in buildings: A case study of the city of Tehran, Iran. *Sustain. Cities Soc.* **2022**, *76*, 103435. [CrossRef]
42. Ma, Z.; Zhao, D.; She, C.; Yang, Y.; Yang, R. Personal thermal management techniques for thermal comfort and building energy saving. *Mater. Today Phys.* **2021**, *20*, 100465. [CrossRef]
43. Zhu, F.L.; Feng, Q.Q. Recent advances in textile materials for personal radiative thermal management in indoor and outdoor environments. *Int. J. Therm. Sci.* **2021**, *165*, 106899. [CrossRef]
44. Sprou, J.; Pun, W.B.H.; Rosenfeld, A.H. Economic comparison of white, green and black flat roofs in the United States. *Energy Build.* **2014**, *71*, 20–27. [CrossRef]

45. Nelson, W.C.; Ott, W.R.; Robinson, J.P.; Tsang, A.M.; Switzer, P.; Behar, J.V.; Hern, S.C.; Engelmann, W.H. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *J. Expo. Sci. Environ. Epidemiol.* **2001**, *11*, 231–252. [CrossRef]
46. Geiger Lynch MacBain Campbell Engineers. 2023. Available online: https://www.geigerengineers.com/about (accessed on 6 August 2023).
47. Bridair. 2023. Available online: https://www.birdair.com/membrane/ (accessed on 6 August 2023).
48. Bridair. 2023. Available online: https://www.birdair.com/membrane/insulated-translucent-membrane/ (accessed on 6 August 2023).
49. Available online: https://www.vector-foiltec.com/wp-content/uploads/2020/12/UL-EPD-Product-Specific-Vector-Foiltec-2019.pdf (accessed on 6 August 2023).
50. Serge Ferrari SA 2018. 2023. Available online: https://www.sergeferrari.com/de-de/produkteproduktreihe-flexlight/flexlight-xtrem-tx30-ii (accessed on 6 August 2023).
51. Temme//Obermeier GmbH. 2023. Available online: https://www.3dtex.de/en/3d-isoskin/ (accessed on 6 August 2023).
52. 3dtex GmbH. 2023. Available online: https://www.3dtex.de/en/projects/ (accessed on 6 August 2023).