Materiali di architettura e di urbanistica

Collana di progetti, piani, paesaggi

La collana, avviata nel 2014 da docenti del Politecnico di Milano, raccoglie lavori di architettura e di urbanistica anche distanti per argomento e impostazione ma sempre improntati al rigore del metodo, alla dimostrazione degli assunti, alla fondatezza e ripercorribilità dei cammini analitici e progettuali. È stato scelto di non assumere limiti di scala e di confine promuovendo così la pubblicazione di studi che spaziano dai temi della dimensione regionale al progetto della cellula residenziale e, di conseguenza, intersecando e confrontando competenze disciplinari diverse. I *materiali* della collana sono destinati a chi, anche privo di radicati fondamenti specialistici, intenda farne uso nella prospettiva d'una architettura e urbanistica di reale cambiamento, come impone l'evoluzione della società, della cultura e delle scienze.

Architecture and Urban Planning Materials

Collection of projects, plans, landscapes

The collection, launched by professors of the Politecnico di Milano in 2014, collects a variety of architectural and urban planning works. Though these works concern a wide array of arguments and settings, they are shaped to the rigor of the method, to the demonstration of assumptions, and to the legitimacy and retracement of analytical and project paths. The decision was made to not adopt limits of scale and boundary, thereby promoting the publication of studies that range from themes of the regional dimension to the plan of a single residential cell. In this way, different disciplinary competences are intersected and compared. The collection's materials are intended for those who, even if devoid of rooted specialized foundations, intend to use them in prospect of an architecture and urban planning of true change, as the evolution of society, culture, and science today imposes.

建筑与城市规划材料

项目、规划和景观集锦

本书在2014年由米兰理工大学建筑与城市研究学院的三位教授推出，收录了多个建筑和城市规划的项目。这些项目涉及了广泛的内容和议题。通过严谨的方法，对假设的论证、重演分析的基础和功能、以及展示项目的过程等来形成最终项目。本书观点并不拘泥于项目规模和范围的限制，而是促进扩展性的研究，范围可从区域性尺度到住宅单元，以应对交叉学科和不同学科的能力。如今随着社会、文化和科学的各方面急需转变，因此书中所提供的材料的目的是在于提供建筑和城市规划真正的前景，即使是对非本专业的认识也将有所启迪。

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DESIGN FOR CIRCULARITY

Experimentation and Innovation for the Construction Sector

Elisabetta Ginelli
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Editors

MIMESIS
Materiali di architettura e di urbanistica

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THE CIRCULAR ECONOMY OF WATER IN SUSTAINABLE CONSTRUCTION. ROOFING AS A RESOURCE

WATER SUSTAINABILITY IN EUROPE. CHALLENGES, ACHIEVEMENTS AND DIRECTIONS

Water is an interconnected and vital resource, spanning from melting glaciers, lakes, and rivers to groundwater and seas. However, pollution, over-exploitation, physical alterations to water habitats, and climate change continue to impact Europe's water bodies and the life that depends on them. Europeans consume billions of cubic meters of water annually for drinking, agriculture, manufacturing, heating and cooling, electricity generation, tourism, and other services, yet freshwater resources are finite (EEA, 2021).

The European Union and its Member States have implemented policies and measures to improve water quality, reduce pollution, and enhance aquatic ecosystems. Remarkable achievements have been made in certain areas, such as bathing water quality, drinking water, and urban wastewater treatment. However, other areas, like wetland conservation and plastic litter in seas, still raise concerns due to worrying trends (Directive 2000/60/EC). Compared to many parts of the world, Europe still has relatively abundant freshwater resources. However, these resources are unevenly distributed across the continent. In fact, it is estimated that about one-third of the EU territory experiences water stress, where demand exceeds available supply for certain periods: despite a 15% decline in freshwater abstraction in the EU between 2000 and 2019, there has been no overall reduction in the areas affected by water scarcity. When we take a broader look, though, the global situation appears to be much worse: at least 4 billion people - 50% of the global population- deal with water shortfalls at least one month of the year. By 2025, 1.8 billion people are likely to face what the Food and Agriculture Organization (FAO) calls "absolute water scarcity" (UNESCO, 2024).

Climate change impacts every region across the globe. Polar ice caps are melting, leading to rising sea levels. Some areas are witnessing an increase in extreme weather events and heavy rainfall, while others face more intense heat waves and droughts. Many regions in Europe are already experiencing more frequent, severe, and prolonged droughts: they cause approximately EUR 9 billion in annual losses, primarily impacting agriculture, the energy sector, and public water supplies. Extreme droughts are becoming more frequent, and the resulting damage is increasing. With a global average temperature rise of 3°C, droughts are expected to occur twice as often, and annual losses from droughts in Europe could increase to EUR 40 billion. The Mediterranean and Atlantic regions would face the most severe impacts (EU, 2021).

On the left:
Detail of the detention roof model set up at MADE Expo (photo by G. Pozzi).

Approximately two billion people globally lack access to safe drinking water today (SDG Report 2022), and nearly half of the world's population experiences severe water scarcity for at least part of the year (IPCC, 2023). These figures are anticipated to rise due to the impacts of climate change and population growth. Only 0.5% of Earth's water is usable and available as freshwater, and climate change is significantly impacting this supply. Over the past two decades, terrestrial water storage - including soil moisture, snow, and ice - has declined at a rate of 1 cm per year, posing major challenges for water security (WMO, 2023). In this global context of water scarcity, the European Union has established comprehensive policies to promote the harvesting and reuse of rainwater, particularly through the Water Reuse Regulation (EU 2020/741). The European Commission strongly advocates for rainwater harvesting as part of its broader strategy to enhance water resource management and resilience against climate change impacts.

This practice is seen as a vital component of sustainable water management, particularly in urban areas where stormwater management is crucial. This regulation sets minimum quality requirements for the safe reuse of treated urban wastewater, specifically in agricultural irrigation, to address water scarcity and improve resource efficiency across member states. It is therefore essential to both collect rainwater and adopt personal and collective behaviours that avoid any form of water waste. Regarding the distribution of drinking water, significant losses are recorded along the distribution network in most of the European countries. In Italy, the distribution of drinking water is managed by regional or sub-regional entities, making it difficult to obtain estimates of the percentage of water lost along the network. According to the estimates published on one of the most important Italian newspapers (Il Sole 24 ore, 2024), in Europe Italy is among the worst countries for water loss, with a rate of 42%; the best performance is by the Netherlands. As for the infrastructure, 60% of the water infrastructure was installed over thirty years ago; 25% is even more than 50 years old.

WATER IN BUILDINGS. BALANCING INVARIANCE AND CONSUMPTION

In Italy, since the 1950s, industrialisation in construction has been a mantra that, with each fluctuation in the building cycles, promises to revive the sector and raises hopes that construction will become an industry comparable to other industries in the country. Unfortunately, this is repeatedly disproved with each recovery cycle!

It is also difficult to define what is meant by "industrialisation": bricks are certainly among the most industrialized products in construction today, but the use of bricks is certainly not the best premise for realizing "industrialized" buildings. Certainly, it can be affirmed that "industrialisation" is synonymous with "quality": an industrialized product and process is undoubtedly one that has higher quality and better sustainability, as extensively demonstrated in (Pozzi 2021), which includes a comprehensive bibliographic review highlighting the benefits on the subject. For example, "IBS buildings are superior to the site-built ones, thanks to the controlled environment of the factory" (Pan, Wei, Sidwell, 2011) and "China is planning to build 6 million dwelling units using IBS as the main way to achieve sustainability in new towns" (Jiang et al., 2018).

There are many methods for evaluating the quality and sustainability of a product or process in construction. Given the relevance of the subject in this research and the significant impact the issue has on the global economy, the relationship these methods have with water has been chosen for analysis here. Many certification systems (LEED, BREEAM, CAM, etc.) assess the relationship that buildings have with water during the usage phase, particularly in terms of consumption. Another possible approach to water involves evaluating the pollution caused by production processes on groundwater or watercourses, but these are more related to the environmental certifications of companies rather than the certifications of products and buildings.

In this context, we aim to highlight how the relationship[1] with water can be a significant parameter for evaluating the quality and sustainability of the construction phase of a building project. Dry assembly using fastening techniques is certainly one of the most interesting methods in terms of sustainability, as extensively demonstrated by (Montiero et al., 2017) in an article in Nature. It can be stated that "...monitoring water consumption in the production process is another important factor, especially considering that some estimates suggest a consumption of between 500 and 3,500 litres of water per square meter of constructed surface"[2]. Therefore, a possible definition of industrialisation that we want to adopt, which represents a paradigmatic approach to contemporary design, is to identify an "industrialized process for construction" as a process that does not use water in any form, either directly or as part of mixtures (even pre-mixed with water), in any operation on-site, and therefore requires no drying time, utilizing exclusively dry assembly fastening systems. It could thus be asserted that less water equals greater sustainability.

From the above, it is evident that dry construction has undeniable construction and environmental advantages during the implementation phase. Additionally, significant advantages are found during the decommissioning phase of the building (a phase often neglected in many sustainability assessments) since these constructions are also dismantable, reusable, and recyclable. No materials are bonded to others, and all can be adequately separated without the use of energy-intensive techniques for separation. Even with regard to our specific theme - coverings - this principle holds true: plastic membranes that are not glued or welded to the support allow for dismantling, reusability, and recyclability, as better described in the following paragraph.

Regarding the issue of water, other aspects of the water cycle in the construction sector must be considered: because of hydraulic invariance, a building should not disrupt the natural percolation of water into the ground. Therefore, it is necessary to design systems (wells or diffuse systems) for reinfiltration; unfortunately, with abnormal rains, which now seem to be the norm at our latitudes, these systems fail: new systems are needed to make the reinfiltration process more efficient (Mai, 2022). Additionally, water is a resource: before reintroducing it into the ground, it is essential to be able to reuse it multiple times; see (Pozzi and Vignati, 2023) for this purpose.

[1] Construction sites in Italy consume (INAIL, 2015):
- 80 - 100 liters per person per day;
- 150 liters per cubic meter for concrete mixes;
- 100 - 120 liters per hour per cubic meter of air delivered per minute for compressors without coolers;
- 1000 liters per cubic meter of washed gravel (if de-sliming is performed with violent jets on rotating or vibrating screens, consumption can rise to 3 - 4 cubic meters per cubic meter of washed material).

[2] INAIL (2015), *Risorse idriche in edilizia: impatto e come ridurre i consumi*.

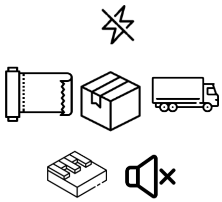
Fig 1. Picture of the detention roof model set up at MADE Expo (photo by G. Pozzi).

WATERPROOF SYSTEM IN A SUSTAINABLE SCENARIO

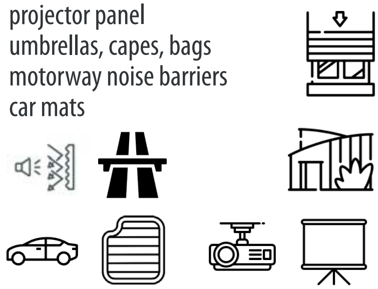
The following paragraph will discuss possible uses of coverings to address these issues. The current market for roof waterproofing systems is rich in alternatives, but the most suitable option for a sustainable approach is the use of TPO-FPO membranes. This solution exhibits superior recyclability, through mechanical or chemical recycling processes, and lower environmental impact. TPO-FPO membranes predominantly consist of thermoplastic polymers, which are inherently less resource-intensive to manufacture compared to Bitumen-based or PVC membranes, which involve hazardous components, such as fossil fuels and chlorine, respectively. Moreover, the durability of TPO-FPO membranes aligns seamlessly with sustainable architectural principles. Engineered to withstand UV degradation, temperature fluctuations, and chemical exposure, these membranes boast extended service lives, reducing the frequency of roof replacements and associated material consumption.

POSSIBLE REUSE

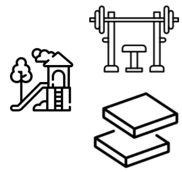
WITHOUT CHANGES
electrical insulation
packaging
anti-vibration membranes



IN PIECES
blackout curtains
facade cladding
projector panel
umbrellas, capes, bags
motorway noise barriers
car mats



CHOPPED
gym or playground flooring



OBJECTIVE

Research for more environmentally sustainable alternatives to roofing waterproofing membranes.

Three possible solutions are:
Modify the geometry and shape of the waterproofing membranes

Provide a service that allows customers to easily install and dismantle their membrane

Re-use membranes at the end of their useful life

BLUE ROOF TYPES:
Blue Roof Detention
temporary detention

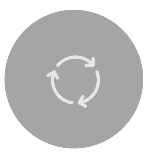
Blue Roof Retention
long-term storage

Blue Roof Green Roof
combines the benefits of a green roof with those of a rainwater management system

WHAT IS BLUE ROOF?

DESIGNED TO CAPTURE, STORE AND MANAGE RAINWATER SUSTAINABLY

SPECIFIC CHARACTERISTICS ALLOW FOR THE ABSORPTION OR COLLECTION OF WATER



PERMEABLE MATERIALS OR INTEGRATED DRAINAGE SYSTEMS, WHICH CONVEY WATER TO STORAGE TANKS

ADVANTAGES

REDUCTION OF THE LOAD ON THE URBAN DRAINAGE SYSTEM

FLOOD PREVENTION

RECOVERY AND REUSE OF RAINWATER

Fig 2. New uses of membranes: from re-use to use-as-service membranes for blue-roof (drawing by W.O. Krawczyk and P.E. Leon).

Fig 3. Possible use and re-use of dismissed membranes: plastic bags, umbrellas, and car mats (drawing by W.O. Krawczyk and P.E. Leon).

In a comprehensive life cycle assessment (LCA) framework, TPO-FPO membranes unequivocally emerge as the optimal choice for environmentally conscious architectural endeavours. It is important to note that currently there is no viable bio-based solution available on the market. Considering the high global lifecycle cost of thermoplastic polymers, this represents a failure in terms of environmental strategies. The research aims to retroactively address each stage in the lifecycle of waterproofing membranes from a circular perspective. It starts by exploring possible reuses of exhausted membranes and identifying additional functions for existing systems. Next, it addresses the materials, investigating bio-based solutions to reduce the chemical component, and considers the business model as a whole.

Reuse-Recycle

Polymeric waterproofing membranes are typically designed for a lifespan ranging from 20 to 30 years when properly installed and maintained, at the end of which, due to UV radiation and other environmental factors, the physical properties of the material have been altered, and watertightness cannot be guaranteed. The remaining sheets of membrane still hold many valuable mechanical properties, which can be exploited through different degrees of physical and chemical treatments. Listed, from least to most extensive, are some of the most common processes that these membranes could undergo:
- Reprocessed: membranes undergo treatments to extend their lifespan
- Composite: membranes are cut in sheets of varying dimensions and combined with other materials, to serve new purposes.
- Particle Boards: membranes are shredded to particles and pressed into boards
- Functionalized: membranes are chemically or physically modified to impart specific functionalities or characteristics for targeted applications.

Exhausted polymeric membranes that come into sheets can be cut, sawn, and combined with other materials to immediately take place in common day to day objects from umbrellas to bags, capes, and car mats. The Swiss based-manufacturing firm Freitag represents an interesting business model in this prospect. The company has been sourcing the raw materials for its practical day-to-day designs, from truck tarps, plastic bottles, and airbags since 1993. By conducting an evaluation of the altered physical properties of the material, and combining it with textiles, they have been able to build a profitable and sustainable business model.

It is also important to note that the discarded membranes may vary a lot in physical conditions, the most damaged ones become particle boards, which are particularly useful for their acoustic properties.

Biobased. Chemical Changes

As previously addressed, the world of dry construction is particularly relevant in terms of circularity due to its qualities of durability and adaptability. By facilitating disassembly and reconfiguration, dry construction systems promote the transition towards a regenerative approach where materials are collected at the end of their life cycle and reincorporated into the built environment with maximum efficiency and minimal waste.

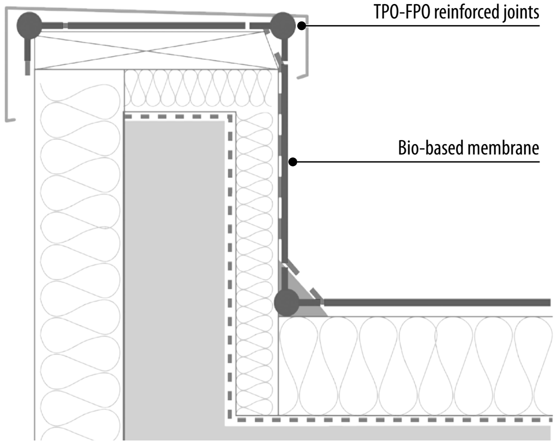


Fig 4. Diagram illustrating the frame structure technology. TPO joints anchor the cornice of the waterproofing layer, enabling the use of bio-based membranes across the remaining surface of flat roof constructions (drawing by W.O. Krawczyk and P.E. Leon).

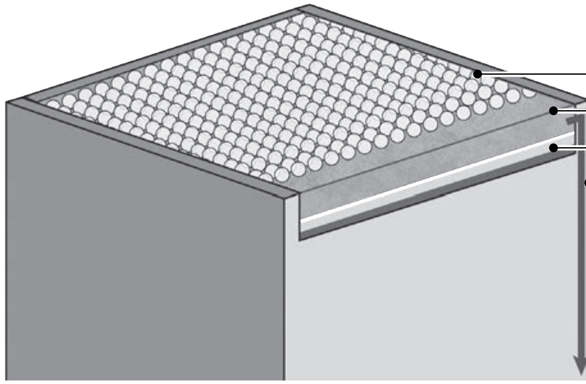
However, this presents a challenge with respect to waterproofing membranes, since typically these systems are glued or fused onto the intended surface, rendering restoration to the original condition unfeasible. However, in the case of polymeric membranes the argument can be made that, given their physical properties, solutions can be developed to reduce the portion of the material glued to the supporting surface, limiting it to strips. The adherence of the membrane to the support, and consequently its watertightness, is guaranteed by the elastic property of TPO-FPO formulations. Furthermore, by studying the most common application techniques and evaluating the mechanical properties of the material, it is easy to recognise that the stress is not equally distributed on the entire surface of the membrane.

The idea of frame structure technology comes from the intuition of reducing the anchor elements to the cornice with a reinforced TPO, leaving the remaining majority of the waterproofing surface to lie flat on the roof. This creates a system that is much easier to disassemble and repurpose, while also opening up possibilities for the use of bio-based solutions, which are typically discarded due to their poor elastic performance.

Retention Roofs. Expanding Functionality

TPO-FPO membranes represent a shift towards sustainable construction practices that emphasize resource efficiency and environmental responsibility. This efficiency extends beyond the potential for reusing materials at the end of their lifecycle to include the enhancement of product functionality throughout their usage. In this context, exploring the concept of retention roofs is particularly pertinent for water resource preservation efforts. Rooftops in cities comprise a significant amount of valuable real estate that can be utilized for energy generation, stormwater management, and plant growth. Retention roof technologies entail the creation of a rainwater collection system on top of the flat roof of a building, which allows for temporary storage and gradual release. This is useful in terms of stormwater management both to prevent water scarcity in drought-prone areas and to avoid flooding in cities that lack proper water drainage systems.

Fig 5. Diagram illustrating a possible retention roof, with floating balls with anti-evaporation function (drawing by W.O. Krawczyk and P.E. Leon).



The controlled release mechanism, which directs the water into the sewer system, is remotely controlled and activated in accordance with weather forecast, to reduce the volume and rate of stormwater entering the sewer system at once, and to further decrease the likelihood of CSOs occurring. Additionally, by allowing sediments and other contaminants to settle, and reducing the flow entering the sewer system, retention roofs also contribute to improving water quality compliance. When it comes to protecting and managing water resources, a great deal of knowledge can be gained by looking at the strategies employed by metropolitan cities situated in arid regions. In 2009, The Los Angeles Department of Water and Power deployed 96 million polyethylene balls (approximately the size of a tennis ball) on the surface of the Ivanhoe reservoir. The black "shade balls" were primarily intended to block the natural formation of Bromate, a carcinogenic chemical, caused by the reaction between sunlight and other chemicals added to the reservoir to prevent algae growth. The reduction of surface level evaporation additionally led to an estimated saving of 1 billion litres of water in one year, which made the experiment an enormous success, later being implemented into the largest water reservoir of the LA County and enforced by the United States Environmental Protection Agency's surface water treatment decree. Given the adaptable nature of this technology, the prospect of downsizing is particularly pertinent in the framework of retention roofs systems to exploit the benefit of an added layer of protection for waterproofing membranes from UV radiation.

Service-based Approach

With proper care, waterproofing membranes can maintain their physical characteristics and achieve a significantly longer lifespan. Although damaged membranes can be reprocessed and repaired relatively easily, the lack of regularly scheduled inspections and the difficulty in detecting maintenance needs often leads to more rapid material deterioration. By shifting from a product-based approach to a service-based approach for waterproofing systems, it is possible to redefine the business model with a circular economy perspective. This service can be marketed as a guarantee of waterproofing over a specified period, during which the company ensures proper installation, ongoing maintenance, and eventual end-of-life management of the materials.

This model encourages companies to take direct responsibility for the lifecycle of their products, including systematic processes for the removal and recycling of membranes at the end of their useful life. By actively engaging in recycling initiatives, companies contribute to the circular economy and reduce the demand for new raw materials.

THE RESOURCE OF A PROBLEM

As is well known, the issue of water in its various aspects (pollution, scarcity, resource, danger, etc.), also due to the rapid climate change of recent years, is becoming predominant in scientific debate and public opinion. Water, in its multiple dimensions, represents a critical challenge that intersects with numerous fields, from environmental sustainability to public health, and economic stability. The increasing severity of droughts, flooding, and water contamination is a pressing concerns that demand innovative solutions and strategic management. Starting from these general aspects, this contribution introduces the topic within the construction sector and proposes some solutions that can transform potential problems into opportunities.

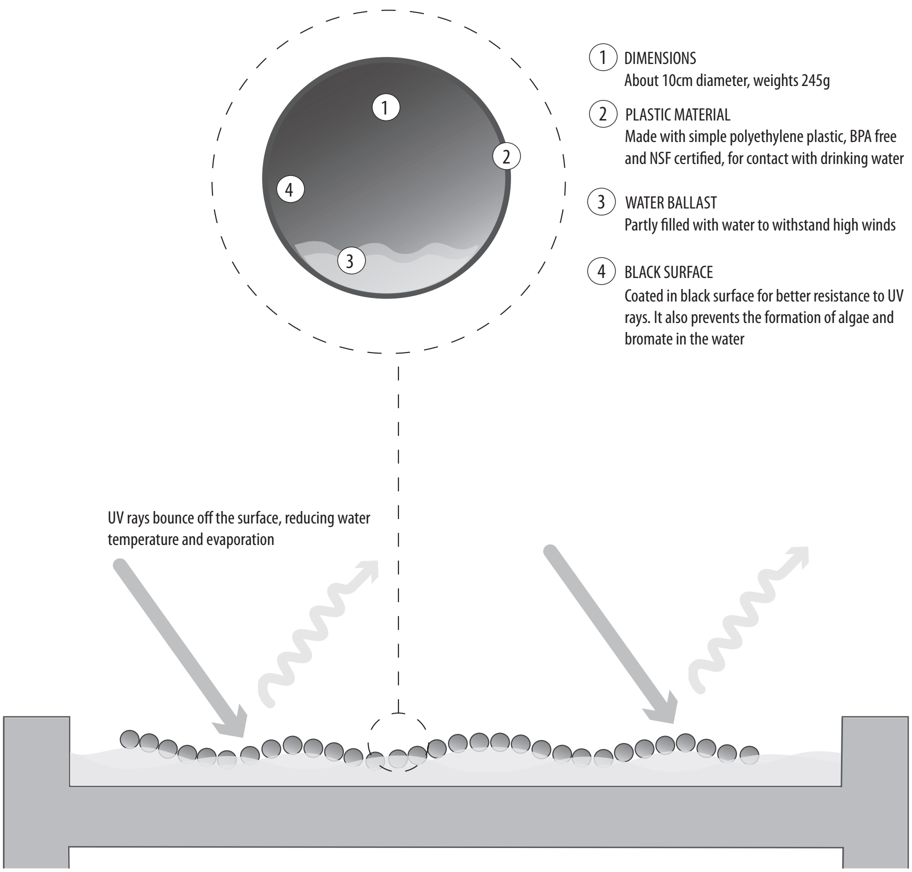


Fig 6. Diagram showing the operating principle of a retention roof (drawing by W.O. Krawczyk and P.E. Leon).

ATTRIBUTION
The paper is the result of shared work between the two authors with the collaboration of Wiktoria Oktawia Krawczyk and Philippe Emil Leon.
MADE Expo research and design team: Matilde Anselmo, Luca Camigliano, Niccolò Gaidano, Wiktoria Oktawia Krawczyk, Philippe Emil Leon, Valeria Mia Suarez Quiroz, Elisabetta Taffa, with the collaboration of Riccardo Villani from Polyglass (2023).

Specifically, it has highlighted the importance of integrating advanced water management practices into building designs and materials. By adopting these practices, construction projects can mitigate water-related risks and enhance resilience against climate impacts. One significant focus of the contribution is on the role of roofing membranes in the circular economy. It has illustrated how, with adequate management and sales strategies, roofing membranes can fully fit into the circular economy and represent a resource for companies and the environment. These membranes can be designed to improve water retention and management, reduce runoff, and enhance the durability and sustainability of buildings.

Therefore, it is now desirable that monitored experiments on the possible solutions be conducted to consolidate and spread practices capable of managing the "water" issue in the best possible way. These experiments should be comprehensive, involving thorough testing and evaluation, and include collaboration between industry experts, researchers, and policymakers. Such interdisciplinary efforts will ensure the effectiveness and scalability of the proposed solutions. By doing so, the construction sector can play a pivotal role in addressing water-related challenges, promoting environmental sustainability, and contributing to a more resilient and resource-efficient economy. Through these coordinated actions, we can foster innovative practices that not only mitigate water issues but also enhance overall sustainability in construction.

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