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Textile Architecture in Transition: Global Trends and Emerging Applications in Pakistan

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Abstract
Textile architecture has emerged as a significant field in contemporary architectural design, offering lightweight, flexible, and cost-effective solutions. This paper explores the evolution of textile architecture globally and its specific development in Pakistan. The study traces the historical origins of textile-based structures, from traditional nomadic shelters to advanced tensile structures pioneered by Frei Otto. It examines the impact of technological advancements, including the use of high-performance materials and computational design, on the growth of textile architecture. In Pakistan, textile architecture has seen gradual adoption, primarily in public spaces, commercial centers, and shading systems, driven by economic and climatic factors. The paper highlights the potential for future advancements in textile architecture within Pakistan's built environment. Through an analysis of existing literature and case studies, this research identifies key opportunities and challenges in the integration of textile-based solutions in contemporary Pakistani architecture.
Keywords: Textile Architecture, Tensile Structures, Smart Materials, Light weight Structures, Parametric Design

Introduction
Textile architecture is an innovative approach in architectural design. It uses flexible, lightweight, and very thin yet exceptionally strong, fabric-based materials for structural application. Textile architecture has a rich history, dating back to early human shelters, and started from a simple tent to a complex modern structure (Gonçalves & Junior, 2023; Shareef & Al-Alwan, 2021). The creation of synthetic fibers and coating materials has greatly improved the durability and performance of textile structures (Mewes, 1993). Among the real features of modern textile architecture are those which relate to the environment and are extremely low in toxicity and such features include transparency, solar reflectivity, thermal insulation, and recycle-ability (Al-Azzawi & Al-Alwan, 2025). The structures have thus helped reduce costs and also encourage energy efficiency through a practice of spanning large areas with a very low consumption of materials. (Shareef & Al-Alwan, 2021). The field continues to evolve, with ongoing research exploring new applications and sustainable solutions for urban environments (Shareef & Al-Alwan, 2021; Gonçalves & Junior, 2023).

Methodology
This study applies a qualitative research approach that incorporates historical

analysis with a case study investigation and a literature review. Secondary data is gathered from peer-reviewed journal articles, books, and industry reports about textile architecture. To compare and contrast technological adoption, appropriateness of a building in the climate, and sustainability considerations, a comparative analysis of global and Pakistani examples of textile architecture is made. The research also injects observational studies regarding the existing textile-based structures in Pakistan to assess its performance and perception by the user. The findings are hoped to bring about a full-fledge understanding of progress, contemporary dynamics, and future potentials of textile architecture in Pakistan.

Historical Development of Textile Architecture

Textile architecture dates back to the time of paleolithic human beings using animal hides and woven mats for shelters. Evidence from yurts and tents indicates other improvements, such as the Mongolian and Bedouin tribes that developed the nomadic lifestyle. (Berger, 2005).

The 20th century brought about industrial development, where architectural legends like Frei Otto and Buckminster Fuller shaped the future of architectural textile works by combining modern engineering with tensile structures. (Otto, 1985). Their works in lightweight and tensile structures opened gates for new-age membrane architecture.

Textile and architecture developments are based basically on materials advancement. It is the discovery of materials like polyester, PTFE, and ETFE that has tremendously improved the strength withstanding of ultraviolet rays and the general strength of textile structures. (Addington & Schodek, 2012).

The rise of advanced materials enabled large tensile structures to be engineered in a Millennium Dome in London or an Allianz Arena in Munich (Addis, 2017). Therefore, these development innovations make textile architecture a possible preference to traditional construction. Recent transformations of architectural fabrics include computational design plus digital fabrication and parametric modeling capability. Other new tools include Finite Element Analysis (FEA), which allows architects to optimize fabric structures for both load-bearing efficiency and aesthetics (Schmidt, 2013), and preliminary resources such as parametric modeling tools, which help in creating complex geometries where energy and material efficiency is optimized by construction waste and other forms of unwanted wasted energy (Oxman, 2014). Besides, the joined use of other self-cleaning materials and different manners of textiles, including photovoltaics, aids in achieving sustainability in textile architecture as well (Bechthold, 2008).

Global Trends in Textile Architecture

Textile architecture is very relevant as a contribution to sustainable design through multiple dimensions. They, therefore, admit much more daylight, hence decreasing the amount of electric illumination needed and thus also decreasing energy consumption (Schneider, 2015). Tensile and membrane construction elements require fewer raw materials per unit of performance; hence, material waste tends to be much lower. Development of recyclable and biodegradable textiles will advance environmental sustainability, even in the context of textile-based structures (Pawlyn, 2016). Buildings that are easy to construct and

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deconstruct can find multiple uses in forms such as temporary buildings, shelter homes post-disasters, and even pavilions for use in events (Hegger et al., 2008). Effective reuse of smart textiles in textile architecture increases photovoltaic and phase-change sustainability by increasing energy harvesting and climate adaptability for buildings based upon textiles (Picon, 2010).

Case Studies of Textile Architecture

International Case Studies on Textile Architecture: Evolution Over Time

Early Developments (Before 20th Century)

Yurts (Central Asia) – Traditional Tensile Structures

Yurts are portable, fabric-covered dwellings traditionally used by nomadic communities in Central Asia, particularly in Mongolia, Kazakhstan, and Kyrgyzstan. Made of a wooden framework covered in felt, they were flexible, durable, and insulated well for a wide range of climates.

Bedouin Tents (Middle East & North Africa) – Traditional Textile Architecture

The Bedouin tent or "Black Tent" is woven from goat hair and is used as a portable tent by nomadic tribes in desert regions. They are designed to protect from extreme temperatures while also enabling ventilation.

20th Century Innovations (1900-1999)

Munich Olympic Stadium (Germany, 1972) – Lightweight Cable-Net Roof

Designed by Frei Otto a revolutionary lightweight and transparent tensile roof structure made of Acrylic coated polyester fabric, spanning the Olympic Park, hung from cable-net structures supported by masts.

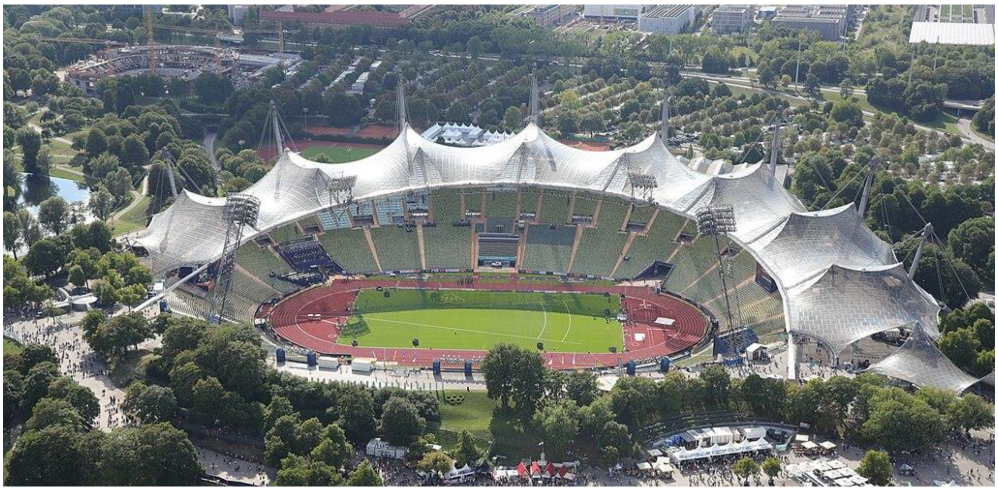

Figure-1
https://en.wikipedia.org/wiki/Olympiastadion_%28Munich%29#/media/File:2022821_Olympiapark_M%C3%BCnchen_by_Sandro_Halank%E2%80%93025.jpg

DEN Passenger Terminal Complex, Denver, Colorado, USA

The passenger terminal complex at Denver International Airport is Fentress Architects most celebrated project. The iconic design is inspired by the Rocky Mountains. The tensile fabric roof structure not only transmit daylight but also helps in reducing demand for artificial lighting and cooling loads. Moreover, use

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of triangular clerestory windows on East and West and use of curtain walls on North and South add visual drama.

Figure-2 Figure-3

https://www.burohappold.com/projects/millennium-dome/ https://fentressarchitects.com/project/den-passenger terminal/

Millennium Dome (UK, 1999)

The world's largest domed-shaped tensile structure, the Millennium Dome was inspired by time and the heavens. Architects from Richard Rogers Partnership and Imagination tracked the trajectories of stars and comets from dawn until dusk, plotting their celestial paths onto early concept models of the Dome. and features a canopy based on cosmic lines of longitude and latitude.

21st Century Advancements (2000-Present)

Allianz Arena (Germany, 2005) – Inflatable ETFE Facade

The Allianz Arena was designed by the architecture firm Herzog & de Meuron, is famous for its color scheme and futuristic appearance. The stadium was home to two teams: Bayern Munich and TSV 1860. Bayern plays in red, TSV in blue, so the architects devised a way in which the stadium could be transformed, glowing like a beacon in different colors from one week to the next. They chose to clad the 75,000-seat stadium in ethylene tetrafluoroethylene (ETFE) cushions that light up in red or blue—or white when the German national team plays.

Figure-4 Figure-5

https://www.herzogdemeuron.com/projects/205-allianz-arena/ https://www.arup.com/projects/national-aquatics-center-water-cube/

Beijing National Aquatics Center (China, 2008) – Water Cube

The National Aquatics Center, also known as the 'Water Cube', is one of the

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most dramatic and exciting sporting venues constructed for the 2008 Beijing Olympic Games. The ARUP's design mimics the structure of soap bubbles, utilizing an Ethyl tetrofluoroethylene (ETFE) cladding that allows more light transmission than glass and is self-cleaning with rainwater.

Khan Shatyr Entertainment Center (Kazakhstan, 2010) – World's Largest Tent Structure

Figure-6
Khan Shatyr Entertainment Centre | Projects

Figure-7
The Eden Project: The Biomes – Projects – GRIMSHAW

This monumental tent structure by Foster + Partners consists of a steel cable net and a three-layer ETFE envelope. It shelters a vast indoor environment from Kazakhstan's extreme climate while admitting natural light.

The Eden Project (UK, 2011) – ETFE Biome Domes

Designed by Grimshaw Architects, the Eden Project includes interconnected geodesic domes clad in ETFE cushions. Each biome replicates different climate zones, using the material's transparency and lightweight properties.

Serpentine Pavilion (UK, Annual Projects) – Experimental Textile Designs

The Serpentine Pavilion series in London commissions international architects to design temporary structures using innovative textile membranes and tensile forms, exploring the boundaries of fabric architecture.

Figure-8
https://www.akt-uk.com/projects/serpentine-pavilion-2016/

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Figure-9
https://www.archdaily.com/1009028/texoversum-innovation-center-allmannwappner

Texoversum, by allmannwappner and Menges Scheffler Architekten (Reutlingen, Germany)
Texoversum in Reutlingen features a modular facade made of interwoven carbon and glass fiber textiles. Created by allmannwappner and Menges Scheffler Architekten, it integrates shading, structure, and transparency as part of a research initiative.

Design District Canteen, by SelgasCano (London, UK)
Designed by SelgasCano, the Canteen combines an ETFE membrane and polycarbonate panels over a light metal frame. It glows at night and creates an open-air, market-like atmosphere.

Figure-10
https://www.archdaily.com/992202/design-district-canteen-selgascano

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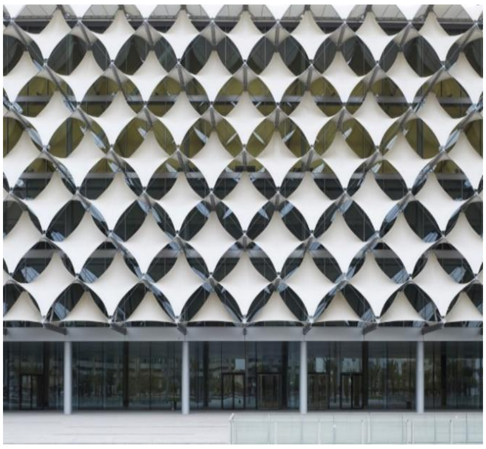

Figure-11
https://archello.com/fr/project/king-fahad-national-library

King Fahad National Library Riyadh, by Gerber Architekten (Saudi Arabia)

Gerber Architekten designed the library's cube-shaped textile skin to reinterpret traditional mashrabiya screens. The design provides solar shading and energy efficiency while blending cultural heritage with modern materials.

Soundforms, by Flanagan Lawrence (London, UK)

Soundforms is a mobile concert hall using PVC-coated polyester and inflatable tensile forms. Developed by Flanagan Lawrence, it offers high acoustic performance and weather resistance for temporary or touring events.

Figure 12
https://www.flanaganlawrence.com/soundforms

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Figure 13
https://www.dezeen.com/2008/06/26/zenith-music-hall-by-massimiliano-and-doriana-fuksas/

Zenith Music Hall, France
Designed by architects Massimiliano and Doriana Fuksas in Strasbourg, France. The interior and exterior of the hall structure are covered with translucent, orange fabric so the building appears solid in daylight but reveals its internal structure when illuminated at night.

Cape Town Stadium, South Africa
Designed by GMP Architekten and Louis Karol Architects, erected for the 2010 FIFA World Cup. This circular building; with its curvy contours blends with its coastal surrounding. The outer skin of stadium is of fiberglass fabric that changes with the light conditions. The roof, which is suspended from the slightly undulating outer compression ring, has been weighed down with glass roof panels to counteract wind suction and has a double curvature to guarantee that the construction is highly rigid despite its light weight and to help drain the rainwater from the heavy downpours typical of the region.

Figure-14 Figure-15

https://www.gmp.de/en/projects/501/cape-town-stadium
https://www.archdaily.com/527272/arena-da-amazonia-gmp-architekten?ad_source=search&ad_medium=projects_tab

Arena Da Amazônia, by Schlaich Bergermann Partner (Manaus, Brazil)
Designed by GMP Architects constructed in translucent fiberglass membrane, tubular steel structure. The arena features a raised podium design with a

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lightweight fiberglass roof that offers shade, natural light, and rainwater collection. Designed for the Amazon climate, it's one of the first stadiums to earn LEED certification, showcasing the sustainable potential of textile architecture.

Minna Tent Structures: A Textile Architecture Perspective

The Minna Tent Structures in Saudi Arabia represent one of the most significant applications of textile architecture in the modern world, showcasing the effective use of PTFE-coated fiberglass fabric to create lightweight, fire-resistant, and climate-adaptive tensile structures. These modular tents, spread across more than 20 square kilometers, are engineered to house millions of Hajj pilgrims in a safe, efficient, and culturally responsive manner. Following a catastrophic fire in 1997, the shift from cotton to fireproof tensile fabrics marked a pivotal advancement in integrating safety, comfort, and environmental responsiveness into large-scale temporary shelter (Mahmoud, 2009). The design aligns with core principles of textile architecture, such as structural efficiency, thermal performance, and urban organization, offering a model for future disaster-relief and high-density housing systems (Koch & Sobek, 2014; Berger, 2005).

Figure-16

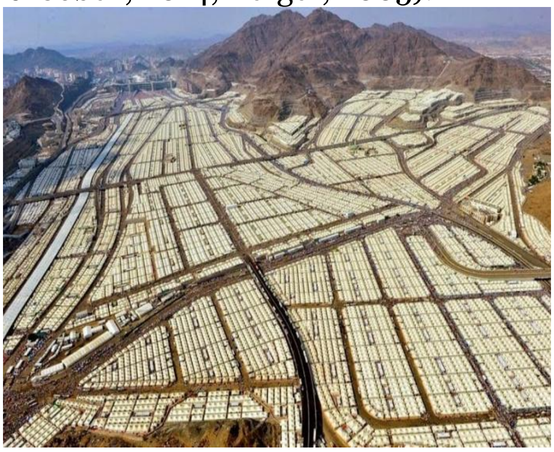

Figure-17

https://www.amusingplanet.com/2014/08/mina-city-of-tents.html

Development of Textile Architecture in Pakistan

Textile architecture applications in Pakistan had not gained much strength until the recent past, but they very likely became stable due to economic values and conforming with the climate of the place. Modern and vernacular construction techniques comprise the architectural scenario of the country, where a rising interest in appropriate, sustaining, and adaptable structures can be noticed. The past reveals native fabric architecture through much-in-use traditional tent structures as practiced by the rural nomad communities of Balochistan and Sindh. The inexpensive movable shelters induce natural ventilation and insulation pan out for severe weather conditions (Ahmed, 2010). In Pakistan, mainstream applications of textile architecture are found in public spaces, commercial centers, and temporary event structures. Marketplaces, airports, and stadiums are increasingly applying tensile fabric canopies. A case in point is the Pakistan Monument Museum based in Islamabad; this museum uses tensile fabric structures for providing shade and improving aesthetics (Hussain, 2016). Textile architectural demand is also driven by environmental factors. Tensile

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membranes shade and cool hot and arid areas of Pakistan, notably in Punjab and Sindh. Meanwhile, concerns regarding ensuring sustainability have also urged architects to take up solutions that are based on the use of textiles in a bid to lower energy and construction wastage (Khan, 2019). Evidence from recent academic research and professional projects in Pakistan presages the feasibility of integrating smart textiles and kinetic facades applied within architectural design. Relatively little cross-adoption of innovative materials and digital fabrication techniques shows that there is an upward trend in the realization of the benefits that textile architecture can bring (Rehman & Ali, 2021).

Case Studies of Textile Architecture in Pakistan

Traditional Marriage Tents in Pakistan: A Blend of Culture and Membrane Architecture

Traditional Pakistani wedding tents, referred to as Shamianas or Pandals, have been in use for centuries as venues for ceremonies. The tents offering functional solutions to accommodate huge crowds. The last few decades have revolutionized the tent structure, initially the tents were of fabric with bright colors and geometric patterns were printed on them but contemporary tensile fabric structures have changed the traditional practices as these are more durable, light weight membranes, waterproof, aesthetically pleasing, UV and weather resistant and are usually treated with anti-microbial coatings for hygiene. These tents are utilized in banquet areas, courtyards, and garden function areas, ensuring the guests' comfort while preserving cultural integrity.

Figure-18
https://www.ssjaincompany.com/shamiana-tent.html

Figure-19
https://www.pinterest.com/rackslahore/

Gaddafi Stadium, Lahore

Gaddafi Stadium, Pakistan's premier cricket venue, has incorporated tensile membrane structures to enhance the spectator experience. The stadium features tensile roofing elements over seating areas, providing shade and protection from the elements during matches and events.

The membranes are designed using PTFE-coated fiberglass fabric, offering high tensile strength, resistance to UV radiation, and the ability to withstand extreme weather conditions. The lightweight structures reduce the need for extensive steel frameworks, minimizing.

Figure-20
https://www.archnet.org/sites/1445?media_content_id=11119

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Figure-21
https://www.instagram.com/p/DDI9LCcIzwq/

Suspended Sanctuaries, Iapex Exhibition, Lahore, 2024
Suspended Sanctuaries, designed by MAS/Architects in collaboration with Amal Fatima Uppal, creates an immersive spatial experience that plays with light, shadow, and perception. The pavilion's design consists of funnel-shaped openings at various nodes, casting precision beams of light that generate intricate silhouettes on the ground. This interplay of radiance and obscurity fosters an atmosphere of mystery, inviting visitors to contemplate and introspect as they navigate through the space.

The structure explores a juxtaposition of mass and levity, appearing weightless despite its suspended form. Delicate metal rods hold the structure mid-air, encased within a fine, translucent fabric that enhances the sense of floating elegance.

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Figure-22
https://www.facebook.com/share/15KZo8CLq7/

Figure-23
https://www.facebook.com/share/1GcZGzeHW8/

Pind Restaurant Lahore

Pind Restaurant, developed by Alfazal Tensile Concept, showcases a distinctive use of tensile architecture to create a culturally immersive dining environment inspired by traditional Punjabi village life. The restaurant's tensile canopy system serves both functional and aesthetic purposes, defining key spatial zones while responding to the local climate.

The design features lightweight, fabric-covered steel structures stretched across open-air courtyards and seating areas. These canopies form fluid, sculptural surfaces that offer shade, diffuse daylight, and enhance natural ventilation. Their soft curvature contrasts with the solid massing of the restaurant's brick towers, creating a dialogue between permanence and impermanence.

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Figure-24 Figure-25

https://alfazaltensileconcept.com/portfolio/pind-restaurant-lahore/

Comparative Analysis of Global and Pakistani Textile Architecture

The global textile architecture has recently come to change due to technological improvements, new reasons for sustainable development, and the need of convenient construction technologies. In Pakistan, the gradual and modest development of textile-based architectural applications responds to the environmental factor in relation to the climatic condition, economic value, and the indigenous applicability.

Comparative Analysis of Global vs. Pakistani Textile Architecture

Aspect	Global Textile Architecture	Pakistani Textile Architecture
Historical Evolution	Evolved from nomadic tents (e.g., yurts, Bedouin tents) to high-tech tensile structures like Frei Otto's stadiums and modern ETFE-clad icons (e.g., Allianz Arena, Water Cube).	Rooted in traditional tents like Shamianas used for ceremonies and nomadic use. Integration in modern architecture is limited to temporary and semi-permanent structures.
Technological Adoption	Incorporates smart fabrics, parametric design, and digital fabrication.	Mostly traditional approaches with minimal use of modern digital or smart materials.
Material Innovation	Uses high-performance materials like PTFE, ETFE, and self-cleaning fabrics with UV and weather resistance.	Common use of polyester, cotton canvas, ETFE , PTFE-coated fiberglass fabric and jute. Advanced materials are scarcely used.
Structural Efficiency	Designed for high strength, flexibility, and minimal material use with advanced engineering.	Functional but basic tensile designs, often lacking detailed structural optimization.
Climate Responsiveness	Engineered with climate-adaptive features	Often lacks thermal control and sustainability features,

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	(ventilation, thermal performance, photovoltaics).	though some regional adaptation exists .
Sustainability Focus	Strong focus on energy efficiency, use of biodegradable materials, and reusability.	Limited application of sustainable principles; needs significant improvement.
Energy Efficiency	Employs phase-changing materials, solar fabrics, and intelligent energy-saving designs.	Primarily relies on passive methods like shading; no notable energy integration yet.
User Perception & Use	Widely accepted and celebrated for aesthetics and function in commercial, public, and sports buildings.	Perceived as low-cost, temporary solutions rather than mainstream architectural innovations.
Case Studies	Allianz Arena, Eden Project, Water Cube, Millennium Dome, Serpentine Pavilion, Mina Tents.	Gaddafi Stadium tensile roofing, Shamiana tents, IAPEX 2024 pavilion, Pind Restaurant tensile canopy.
Future Potential	Focused on AI-driven responsive textiles, sustainability, and digital fabrication.	Increasing interest in textile architecture, with potential in climate-responsive design needs research, funding, and awareness.

Conclusion

Textile architecture has undergone a transformative journey globally, evolving from simple nomadic shelters to advanced tensile and membrane structures that integrate sustainability, aesthetics, and cutting-edge technology. This evolution has been significantly influenced by material innovation, digital design tools, and environmental considerations. In contrast, Pakistan, despite its deep-rooted traditions in textile-based construction and a climate conducive to lightweight structures, has not yet fully embraced these advancements.

The application of textile architecture in Pakistan remains limited, often confined to temporary installations and utilitarian functions. However, recent interest in climate-responsive design and sustainable construction indicates a growing awareness of the potential benefits textile structures can offer. Pakistan needs to invest in research, promote interdisciplinary collaboration, and encourage the adoption of modern materials and construction techniques to bridge the gap with global trends .

Future development should focus on exploring high-performance fabrics, improving climate adaptability, and evaluating the socio-economic impact of textile solutions in urban and rural contexts. With the right strategic direction, textile architecture in Pakistan can evolve from traditional practice into a forward-looking, sustainable design paradigm.

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