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ArchiTextile: A Review on Application of Textiles in Architecture

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ABSTRACT

The use of next generation advanced textiles materials are now accepted and preferred over conventional building materials by the architects due to unique characteristic features of textile materials contributing towards improving overall function, aesthetics and expressiveness of the built structures. In modern architecture, the high performance textile materials are appreciated and adopted for a wider application gamut such as self-cleaning maintenance free structures, fabric canopies, energy efficient structures, high performing façade, energy harvesting curtains, flexible mega-structures, responsive phase changing materials, air-supported fabric structures, thermal balancing, green roofs, smart living spaces, acoustic applications, advanced building materials, textile membranes and constructing living spaces in extreme weather conditions. The textile based architecture is fast and easy to erect, needs less maintenance, cost effective and can replace metal and other conventionally used construction materials. The study focuses on exploring the contribution of advanced textile materials application areas in modern sustainable architecture. The study also aims to highlight the key characteristic features of these uniquely engineered advanced textiles which make them suitable over conventionally used building materials.

Keywords: Architextile, advanced textiles, sustainable architecture

1. Introduction

The use of textile materials and technologies in Architectural applications confronts lack of interest by the architects due to many unsuccessful attempts to incorporate textile based materials by the architects between 1956 and 1970 [1]. There exist different reasons explained by the expert architects on minimal use of textiles in architectural applications. Many architects justify this through citing the reasons behind that includes objection on durability & strength of textiles, lack of fineness, prone to attract more dust & dirt, less life, poor response to serve climatic conditions, resist the flow of air, and hinder light [2-3].

The inception of technical textile products in diverse fields of functional application, replaces gradually the traditionally used materials over time with the advanced textile materials in architectural applications [4-5]. In the last few decades the architectural research in using advanced textile materials focuses on the integration of textiles with smart sensors to provide promising architectural solutions which includes high performance media façade, fabric formwork & structures, energy efficient smart curtains, textile tectonics and improved acoustics features [6-13]. The expert architects experienced that PVC (poly-vinyl chloride) is the best cladding material after profound research [14]. The woven glass fiber coated with silicon and PVC (poly-vinyl chloride) are commercialized and extensively used in many architectural projects. These two textile materials are appreciated by architects and used in building structures due to their properties concerning daylight. The use of ETFE (ethylenetetrafluoro ethylene) and PTFE (polytetrafluoroethylene) is appreciated by the expert architects as advanced façade material. The use of phase changing next generation materials contributes towards sustainable architecture through improving energy efficiency of buildings. Moreover, polymeric material polyester fabrics are used for acoustic insulation, woven metallic material are used for constructing façade , upholstery fabrics made of woolen materials, ceramic fabric for filtration applications.

The current study reviews and focuses on the use of advanced textile materials in improving overall performance of architectural structures. It was reported that the use of advanced textile materials benefited the field of architecture through resolving many imperatives issues confronted in using conventional materials. The study reviews the use of next generation advanced textile materials in architecture such as phase changing high performance architectural membranes, textiles for high performance façade, self-cleaning maintenance free fabric structures, acoustic insulation, low cost living spaces in extreme weather conditions, advanced building material, responsive interior applications, thermal balancing using air cavities and multilayered structures and green roofs.

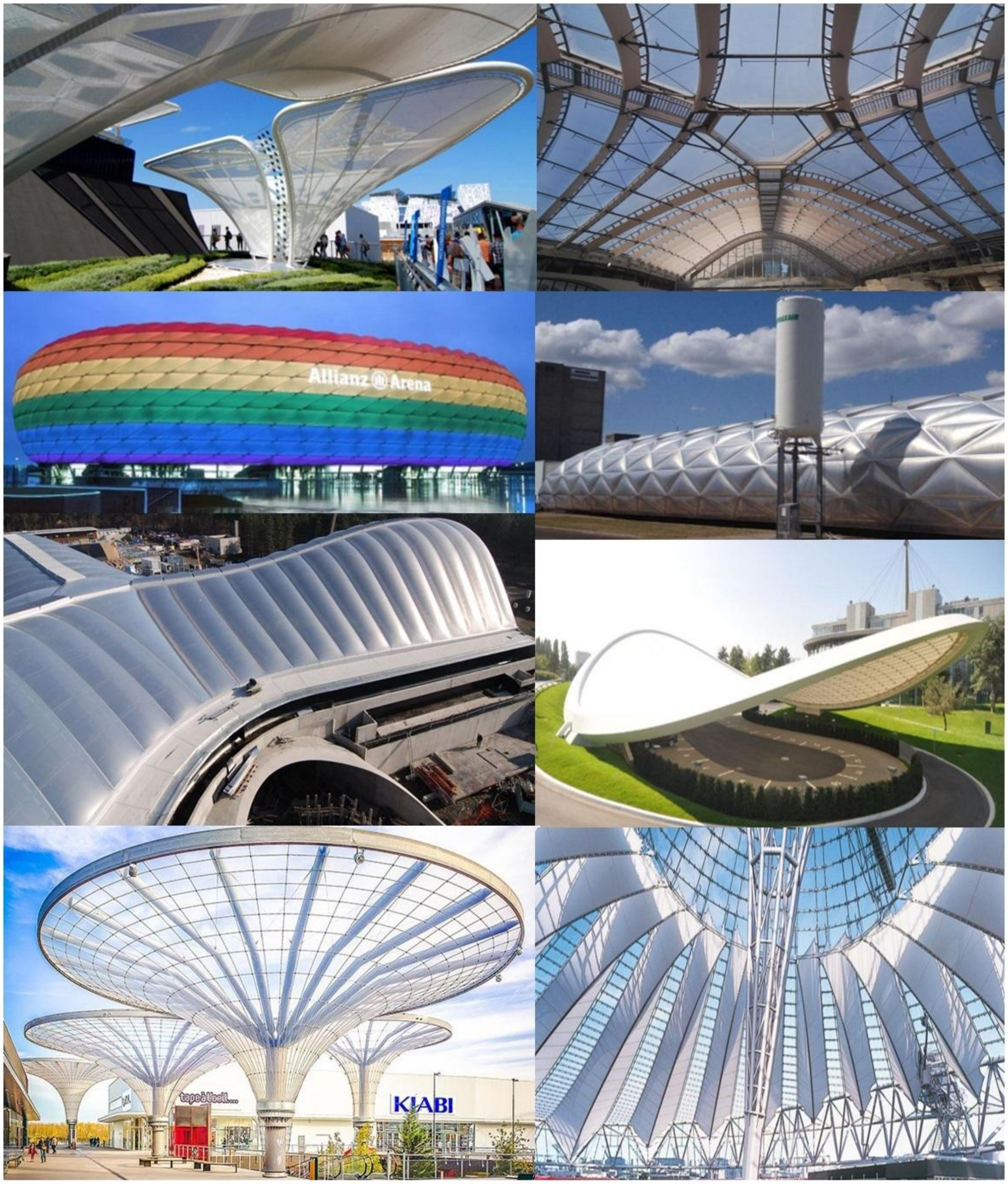

Figure 1: Textile based structures in architectural applications *(Source: Taiyo Europe)*

2. The use of advanced textile material in various architectural applications

Textile materials are gradually emerging as next generation solutions for various architectural applications through improving functional & aesthetical aspects due to characteristic features such as light in weight, low maintenance, flexible structures, responsive nature, energy efficient, cost effective and provide freedom to choose right materials as per requirements. The PVC coated polyester inexpensive building material, PVC nylon used to construct air supported structures, PTFE glass which is stronger & durable compared to PVC polyester, silicon glass, ETFE foils, mesh reinforced films of various textile materials, coated and multilayered textile membranes are some of the most commonly used advanced textile materials providing highly engineered solutions for various architectural applications discussed under current review study in detail.

2.1 Phase changing textiles as high performance architectural membranes

The thermal performance of architectural membranes can be improved significantly as per the requirements by using phase change materials [15-16] absorb or release a large amount of latent heat when they confront a change in their physical state. The most popularly used phase changing materials include paraffins, organic materials, eutectics and salt hydrates including sodium sulfate decahydrate. A phase change from a solid into a liquid on exposure of a material specific temperature is a common phenomenon in phase change materials. The latent heat absorption during melting (solid to liquid) and latent heat is released during cooling reverse phase change (liquid to solid) will take place within the same PCMs material.

The potential application areas of phase change materials as high performance architectural membranes includes advanced tensile structures, emergency shelters, energy efficient façade buildings, greenhouse coverings and swimming pool covers. It was reported that PCM treated silicone rubber coated fiberglass fabric is highly suitable for constructing different types of tensile structures. Due to heat flux control the use of PCMs helps manifold through optimizing heating and air conditioning requirements [17]. PCM treated façade membranes will be opaque in absence of sunlight and translucent during daytime. Furthermore, such façade membranes not just provide privacy to occupants but also use natural light to optimize the artificial light requirements. Hence, the uses of PCMs treated façade contribute towards sustainable architecture through improving energy efficiency of buildings [18]. It was reported that the PCMs heat flux control feature is beneficial for plants grown in a greenhouse. The overheating problem of inside space can be resolved by the use of PCMs in greenhouse applications and the use of PCMs also contribute in making greenhouse building energy efficient [19]. The PCM treated silicone rubber coated fiberglass membrane is also used in constructing emergency shelters with improved thermal comfort [20].

According to the researchers, the smart materials are highly engineered next generation materials that respond upon sensing their environment [21]. Smart memory textile materials have exceptional ability to transform the modern architectural structures envelope in making them more dynamic and sensitive towards micro environmental changes. The confluence of conventional textile materials with the advanced smart materials leads to improve their performance in a passive or active way, utilizing the energy of the sun and promising maintenance and durability [22].

2.2 Textile materials as advanced high performing façade in architecture

It was found that for a building with approximately 50 years of service life, the share of operational energy is about 85% to 95% of total energy use [23]. Thus, the energy efficient buildings will automatically reduce the requirement of operational energy [24]. A high performing façade is required in the design and building energy efficient structures. The construction of high performance energy efficient buildings will result in improved natural daylight, better ventilation due to desired heating and cooling load and improved overall productivity [25].

For building structures, a right material selection will lead to multiple advantages including low environmental impact, durable

& compatible with complementary building materials and low maintenance [26]. The next generation advanced textile materials witnessed immense popularity in previous decades as they offer highly expressive, aesthetically appealing and functional architectural solutions. The textilization of light as a new architectural strategy highlights the potentials of media façade.

Figure 2: Advanced high performing fabric façade *(Source: Taiyo Europe)*

These textile materials shorten the gap between structure and performance. The advanced textile materials used in building façade are usually a coated mesh which reduce the energy consumption dramatically and provide solar protection as well as allow us a view out [27]. The popular textile materials used in building façade are PVC coated polyester, ETFE (ethylenetetrafluoro ethylene) and PTFE (polytetrafluoroethylene). PTFE is also popular as Teflon among professionals.

Hence, a high performance façade in low energy building design using advanced textile materials is a sustainable architectural approach.

It was found that the ETFE and PTFE play a significant contribution in high performance façade of energy efficient buildings. The conventionally used materials in glazed façade are now being gradually replaced by the advanced textile materials due to improved daylight utilization and thermal insulation at a minimal maintenance cost. Hence, advanced textile façade contribute towards making future buildings more energy efficient by optimizing the operational energy of a building resulting in relatively less emission of greenhouse gas [28].

2.3 Advanced textiles for smart building interior applications

The recent advancement in textiles result in innovation in interior applications such as smart energy harvesting curtains, improved distribution and regulation of natural daylight, optimizing indoor climate, improved regulation of the sound [29], intelligent materials for resilient homes and responsive light-emitting smart interactive materials used in futuristic architecture. Furthermore, the selection of fiber, fabric weave, fineness, pattern and number of layers in indoor screening significantly influence the natural daylight and solar energy utilization as textile materials diffuse light and reduce the glare [30]. The use of advanced textile materials help in optimizing the requirements of natural light as per the building energy needs which can be done by using a translucent mesh fabric in PVC coated polyester fabric.

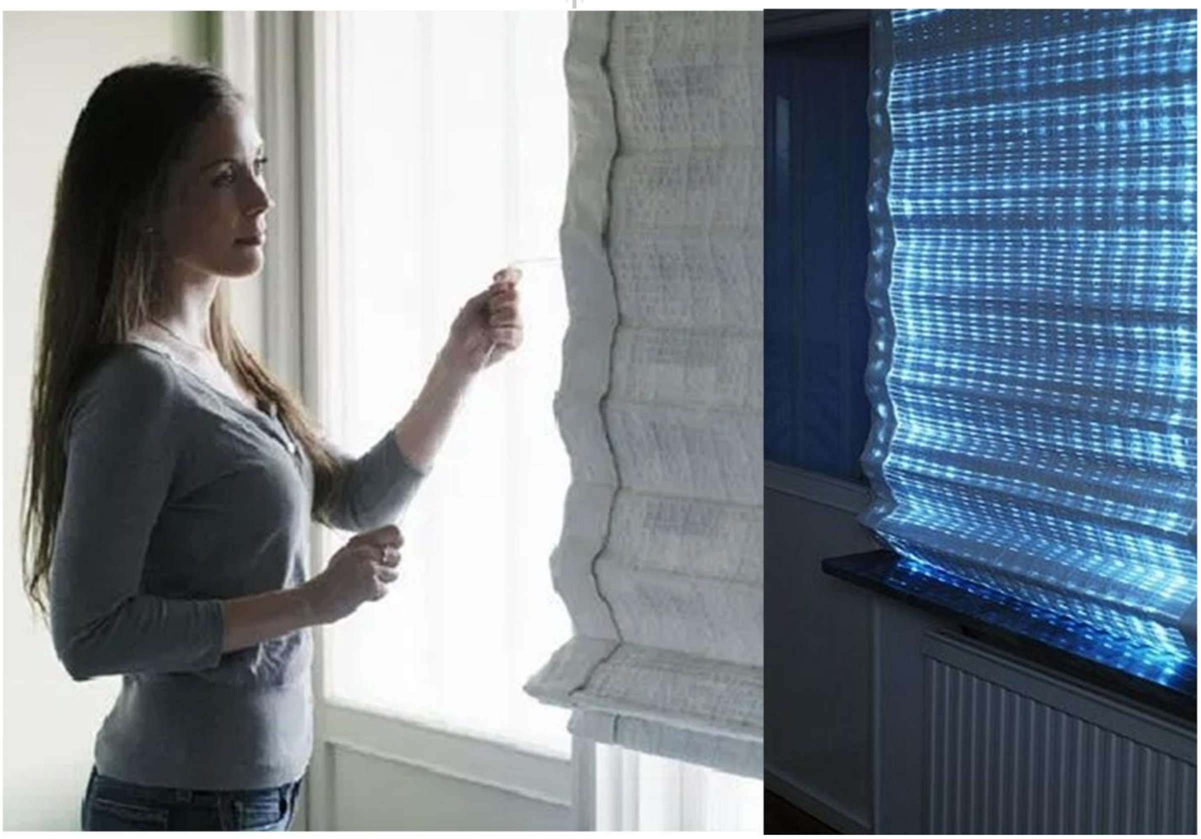

Figure 3: Energy harvesting curtains © Interactive Institute

The electro-active smart polymers are sensitive to the environmental conditions and behave accordingly [31]. The responsive smart textile materials were found helpful in development of a self actuating ceiling surface that can alter its shape on sensing environmental conditions including wind condition [32]. The integration of smart sensors with advanced textiles results in development of energy harvesting curtains. In an energy harvest curtain solar cells along with optical fiber are used to enable curtains harvest energy from the sun during the day and utilize later during night time [33].

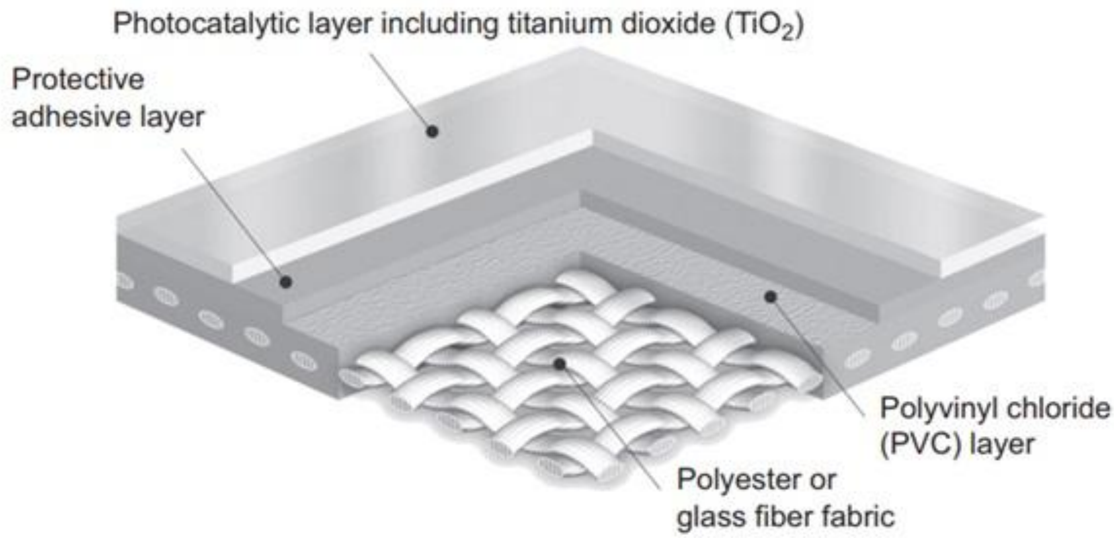

Figure 4: Smart coated multilayered self-cleaning textiles with PVC membrane [34]

2.4 Application of textiles as advanced building material in architecture

The textile materials mostly used in architecture includes silicon coated fiberglass, high density polyethylene, Teflon coated fiberglass, vinyl coated polyester, woven PTFE and ethylene tetrafluoroethylene. Teflon coated fiberglass known as PTFE is an excellent tensile roof material manufactured as per American Society for Testing and Materials ASTM E 108 & ASTM E84 standards with a lifespan of approximately 25 years. PTFE has an excellent temperature, chemical and weather resistance contributing towards its strength and durability. Silicon coated fiberglass is non-combustible, more environment friendly and inexpensive compared to standard PTFE. Vinyl coated polyester is the most cost effective membrane building material for architectural umbrellas. Vinyl coated polyester is soft, pliable and cost effective compared to PTFE or ETFE with a lifespan of up to 25 years. Woven PTFE offers an excellent combination of durability, strength and flexibility. A high-density polyethylene (HDPE) fabric provides biaxial stability under load, high tensile strength, UV stability, high UV absorption, a Class A fire resistance in accordance with ASTM E-84 and has a up to 10 years of lifespan [35-36].

Figure 5: Air supported fabric based structures (Source: DUOL)

The development of advanced textile material such as ethylene tetrafluoroethylene (ETFE) by Du Pont proved beneficial for air-supported fabric structures due to its characteristic features. The polymer ethylene tetrafluoroethylene is a lightweight coating offering good heat resistance, abrasion resistance and resistance to friction within a wider gamut of the temperature [37]. In comparison to glass, ETFE is found stronger and lighter and replaces conventional material for greenhouse glass. Fiber reinforced composite materials have numerous advantages over conventional materials due to advances in key characteristic features such as exceptionally high fatigue resistance, higher strength to weight ratio, high stiffness to weight ratio, no catastrophic failure, minimal thermal expansion, good resistance to chemical and environmental factors. Due to the unique features offered by these advanced fiber reinforced composites are suitable for various architectural applications as per the requirements [38]. It was found that solid-wood textile based advanced architectural materials have many advantages including excellent lightweight construction, versatile functional applications and possibilities of different forms, strong & flexible. Hence, the use of such uniquely designed textile based architecture results in constructing aesthetically appealing, functionally more effective and at the same time improving overall expressiveness [39-40].

2.5 Advanced functional application of layered textiles in Architecture

Polypropylene protection mat sandwiched between a waterproof membrane and drainage mat followed by a filter sheet is extensively used as base material for constructing the green textile roofs. It was found that the green roofs are cost effective, requiring low maintenance and easy to install multilayered functional textiles skins. Green textile roofs contribute towards environment friendly build structures offering unique aesthetic features. There exists many benefits of green architectural roofs at ecological, societal and economical levels. Green roofs constructed using advanced layer textiles provides better air quality, promote biodiversity, optimize the requirements of sewage system, act as buffer for rainwater, reduce the urban heat island effect, help in optimizing sound pollution by providing sound insulation, reduce the energy requirements associated in cooling a building in hot weather and improve overall aesthetics of architectural structures [41-47]. A green textile roof significantly contributes in improving microclimate of the surrounding environment; it also prevents heat loss in winter and at the same time keeps buildings relatively cooler in summers [48]. It was found that the use of textile based green roofs result in reduced precipitation runoff [49].

Figure 6: Green textile roofs multilayered structure [50]

2.6 Application of textiles in constructing low cost living spaces

The "yurt" or "ger" is among one of the earliest examples of the use fabrics for constructing low cost living spaces by nomadic tribes of Eurasian steppe. The yurt is a portable round tent which is covered with thick skins or woolen felts/fabrics, providing heat insulation and creating indoor microclimate in extreme weather conditions of Siberia and Mongolia in central Asian steppe. It was estimated that these constructions were already used by Mongol tribes 2500 year ago. These portable living spaces were transported from one place to other using horses, yaks in colder regions and camels in desert areas. The wooden parts of these constructions are planned & erected by men whereas women prepare the felt coverings for the yurt [51-54]. The tipi is similar to the yurt, the demountable structures used by the Native American inhabitants of North America. It requires less than an hour to construct a tipi structure [54].

The shrinking of living spaces in many countries is due to the high cost of land available for the structural development [55]. Hence, there exists a strong need for low cost portable or non-portable living spaces which are easy to erect in a short time. Such low cost living spaces are extremely helpful in extreme weather conditions by providing protection from temperature, snow, rain, dust, and wind. PVC Coated polyester fabrics and other textile membranes are being used in construction of such structures. Also, air supported structures along with the use of textiles play an important role in development of low cost portable housing which can be erected speedily.

2.7 Application of textiles as functional acoustic material in architecture

The adverse effect of high noise from many sources has been observed on human health and behavior which includes increased stress, insomnia, cardiovascular illnesses, high blood pressure, variation in behavior, reduced work efficiency and possible loss of hearing either temporary or permanent. There exist many urban sources of undesired sound which includes vehicles, automobiles, trains, aircrafts, industrial activities, construction sites, electricity generators and other operations where mechanical rubbing of two surfaces occur [56-62]. Hence, all the aforementioned activities producing excessive sound cause noise pollution. The noise pollution is identified as a serious global issue affecting the health of billions of peoples by the World Health Organization [63-64]. The commercial structures such as supermarkets, apartments, auditoriums, schools & colleges, and dining places need sound control systems/ mechanisms to avoid excessive sound generation [65].

It was found that the use of next generation textile materials & multilayered membranes can be used for acoustical applications to reduce significantly the effect of sound through effective absorption mainly in automotive, residential, industrial and commercial applications [66-67]. The use of advanced textile materials is highly appreciated by many famous architects by incorporating different types of textiles as a media for architectural acoustical application. The purpose of architectural acoustics is to optimize sound control inside a structure or a building such as auditoriums, residential buildings, concert hall, restaurants, recording studios and theatres [68]. The textile based acoustic materials are required for specific architectural applications requiring lightweight fabrics for building structures. Textile materials such as lightweight fabric membrane of ethylenetetrafluoro ethylene (ETFE) pillow have interesting sound optimization properties due to presence of air spaces, inherent thickness, layering and weight. Also, Texlon Cladding System is a pneumatically stressed foil cushion of ETFE provides reduced rain noise and observed less drumming effect of the rain. The tensile fabric membranes are considered as acoustically transparent and do not absorb sound significantly. The sound can travel through and a very little sound is reverberated back [69]. The textile based acoustic materials are fibrous, multilayered, porous, felts and non-woven materials [70-72]. The noise insulation properties of such textile based materials depend on material thickness/fineness, elastic modulus, pore size distribution and flow resistance. The advanced flexible and lightweight textile structures were found more suitable for low frequency sound waves compared to highly stiffer materials of same thickness [73-75].

Although there are different kinds of several lightweight porous sound absorbing materials available, the effectiveness of such materials at low to medium frequency sound is relatively poor. The application of nano-fiber based advanced textile material in many other fields including architecture has shown promising results for low frequency sound absorption [76-79]. The sound absorption properties of such advanced textiles depend on many factors such as fiber properties & structure, fiber fineness, thickness of material, density, air permeability, pore size & pore size distribution [80]. Interestingly, the acoustic properties of micro-fiber fabrics were found to be superior compared to the conventional fabrics of same thickness and weight [81]. The demand of natural acoustic materials is now gaining momentum due to environmental friendly nature and problems associated with the synthetic textile materials. The natural fibers used for acoustic applications are bast fibers (including flax, hemp, and jute), kenaf, agave, coir, wool and bamboo [82-83]. Whereas, the synthetic fibers used for acoustic applications are polypropylene, polyester, viscose due to fiber uniformities and acceptable physical properties.

3. The future of Architextiles and challenges ahead

It was observed that, keeping in view the current and growing demand of advanced textile materials as different components of fabric based architecture, textile based architecture will surely witness the continual growth due to characteristic features of such uniquely engineered materials in improving various aspects of aesthetical and functional architectural applications. The research & development in the field of technical textile manufacturing including commercially available micro-fiber fabric and nanofabric materials with integrated micro sensors results in offering numerous smart solutions in the area of fabric based architecture. It was found that due to good daylight transmission, comparatively low maintenance cost and better thermal insulation textile façade should be considered over traditionally used materials for constructing energy efficient buildings.

There exists a strong need to improve awareness among architectural communities across the world to resolve issues related to cost versus benefits of using textile based materials for building construction due to lack of technical knowhow related to selection of right textiles for architectural applications. Hence, architects in collaboration with fabric specialists may together decide which kind of fabrics, membranes, smart materials, acoustic fabrics, phase change materials, smart memory materials, fabric façade to be used in building construction after considering all the aspects related to durability, life cycle, energy efficiency, building environment, environmental impact, day light utilization, maintenance and costing of textile materials [84-87].

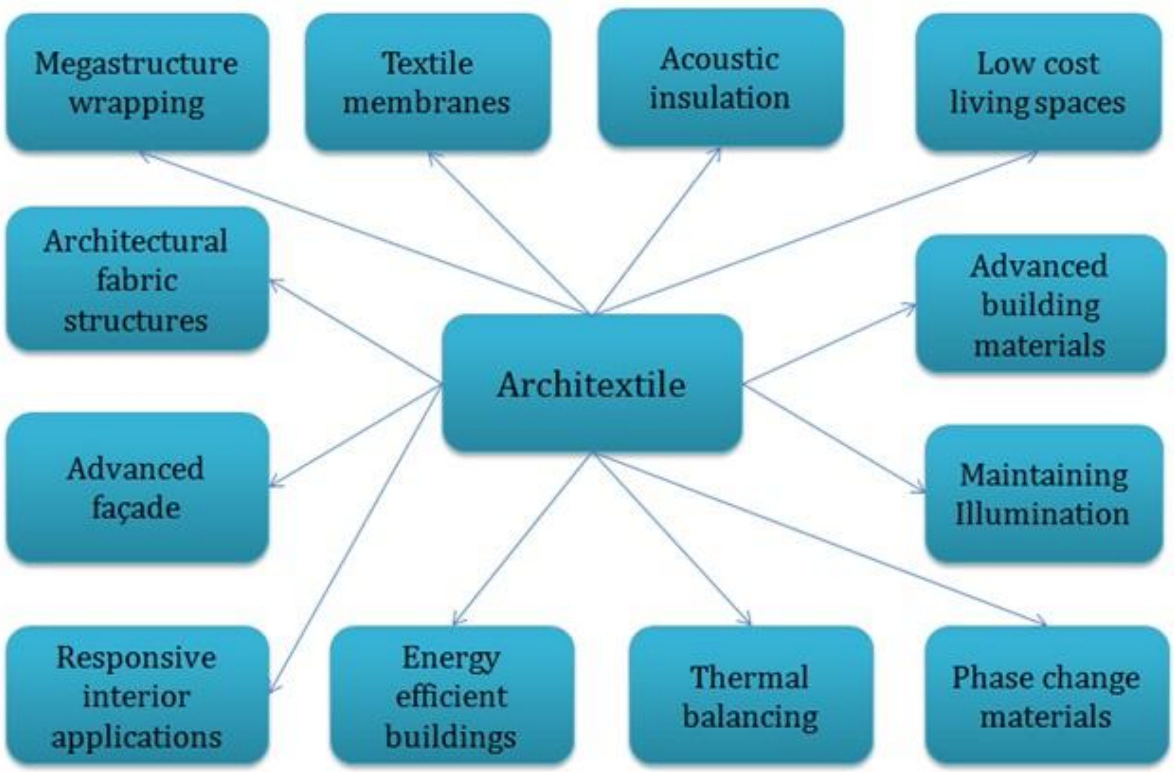

Figure 7: Functional advancement in application of textiles in architecture

4. Conclusion

Textile materials are an integral unique solution to building better places to live in the present and for future generations due to characteristic features such as light in weight, strong & durable, cost effective, energy efficient, self-cleaning with low maintenance, faster to construct, easy to reconfigure, improved daylight utilization and provides highly customized building structures. Moreover, these uniquely manufactured advanced textile materials improve functionality, aesthetics and overall expressiveness of the textile based architectural structures by maintaining desired microclimate inside a building, making buildings energy efficient, environment friendly, and more sustainable place to live in. The use of textile based materials in architecture also results in reducing the power requirement of a building by optimizing daylight utilization. Textile based high performing façade have many benefits over conventional materials such as creative freedom to architects, optimize glare, improved durability, improve energy efficiency of a building, lightweight, weather resistant, ultraviolet resistant, fire resistant, cost effective and improved acoustic performance. Some other uses of textile materials in architectural applications include constructing portable low cost living spaces for extreme weather conditions, mega-structure wrapping, textile membranes, responsive interior applications, fabric based air supported structures, green roofs and development of green building structures. Hence, it was observed that highly engineered textile materials are increasingly appreciated due to their significant contribution in various architectural applications to bridge the gap between performance and structures.

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