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THE ROLE OF SILICONE IN ENHANCING THE WEATHERABILITY OF FACADE MATERIALS

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ABSTRACT

Building facade materials are continuously exposed to various environmental factors that can accelerate degradation, impacting their durability, aesthetics, and overall performance. The role of silicone in enhancing the weatherability of these facade materials is emerging as a potent solution to these challenges. This comprehensive review investigates the unique chemical aspects of silicone that contribute to improved resistance against harsh environmental factors such as ultraviolet (UV) radiation, temperature fluctuations, and precipitation. The discussion covers how silicone's intrinsic properties, including its excellent UV stability, thermal resistance, and hydrophobicity, can significantly increase facade materials' longevity. The article further examines innovative silicone technologies and their potential to enhance facade weatherability. By providing a chemical understanding of silicone's weather resistance properties, this review contributes valuable knowledge to the industry, enabling the development of more durable, weather-resistant facade materials. This could result in longer-lasting structures, reduced maintenance costs, and more sustainable building practices in the future.

1. INTRODUCTION

The facade, a critical component of any building, plays a key role in determining its aesthetic appeal, energy efficiency, and durability (Blocken et al., 2013). Facades serve as the interface between the building's interior and the external environment, playing a crucial role in controlling heat gain, light penetration, and overall energy consumption (Htet et al., 2023). This external interface is continually exposed to environmental elements, posing a persistent challenge due to weathering and other related factors (Gomes et al., 2022).

Over time, the facade materials experience degradation due to exposure to ultraviolet (UV) radiation, temperature fluctuations, and precipitation (rain, snow, etc.) (Ferreira et al., 2021). This degradation can lead to an assortment of issues, such as discoloration, loss of material integrity, and a decrease in overall building performance (Eleftheriadis & Hamdy, 2018). Therefore, the pursuit of weather-resistant materials for facades is a central theme in contemporary architectural and materials science research.

Within this context, the introduction of silicone into facade materials has emerged as a potent solution to these challenges (Okokpujie et al., 2022). Silicone, with its unique chemical composition and properties, offers the potential to enhance the weather ability of facade materials substantially. It can contribute to improved resistance against UV radiation, thermal variations, and moisture-related damage, significantly increasing the materials' longevity and performance (Pizzatto et al., 2021).

This review aims to shed light on the role of silicone in enhancing the weather ability of facade materials, discussing its unique chemical properties, practical applications, and potential future developments in the

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field. Recent studies have shown the critical role of silicone in enhancing facade materials' weatherability, particularly in terms of adhesion and cohesion under various environmental conditions (Šimáčková et al., 2014). By enhancing our understanding of silicone's role in facade materials, we can contribute to the development of more robust, longer-lasting, and cost-effective construction practices (Tobin et al., 2020).

2. LITERATURE REVIEW

Silicones, polymers consisting of alternating silicon and oxygen atoms with organic groups attached to the silicon atoms, have been utilized in various capacities since their invention in the early 20th century (Chen et al., 2009). More recent advancements in silicone technology have included innovative composite materials designed for specific applications. For example, the development of bismuth-silicone composites for radiation shielding in medical applications has shown significant potential, demonstrating the versatility and adaptability of silicone-based materials (Mehnati et al., 2019). Figure 1 illustrates the chemical structure of silicone, highlighting its unique Si-O backbone and the attached organic groups that contribute to its weather-resistant properties.

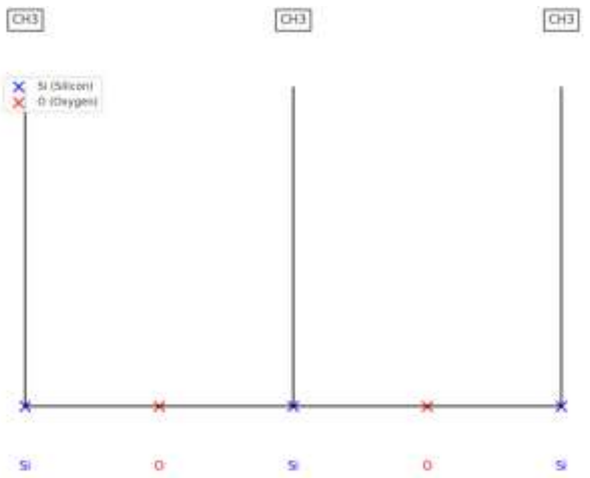

Figure 1. Chemical Structure of Silicone

The application of silicone in facade materials began to gain attention in the mid-to-late 20th century. Silicone sealants were one of the earliest applications, used primarily for their ability to form durable, flexible, and weather-resistant seals. They became widely recognized for their exceptional resistance to environmental conditions, leading to their application in various industries, including construction (Švajlenka & Kozlovská, 2018).

The application of silicone in facade materials began to gain attention in the mid-to-late 20th century. Silicone sealants were one of the earliest applications, used primarily for their ability to form durable, flexible, and weather-resistant seals (Han et al., 2007). Since then, silicone usage has expanded to include protective coatings, adhesives, and even integral components of certain facade materials (Subramani et al., 2018).

Over the last few years, significant research has been carried out on the weatherability of facade materials enhanced with silicone. Sangermano et al. (2014) found that silicone coatings provided superior protection to concrete surfaces exposed to UV radiation and temperature fluctuations compared to traditional coatings. Similarly, Biloria et al. (2023) reported that silicone-enhanced facade materials demonstrated improved weather resistance in marine locations, a traditionally challenging environment due to high levels of moisture and salinity.

In addition to these specific applications, broader studies have confirmed the benefits of silicone for weatherability. For example, a review by Bollmann (2017) underscored the role of silicone's inherent chemical properties – including UV stability, thermal resistance, and hydrophobicity – in enhancing the durability of various facade materials.

Moreover, recent research has started to investigate the potential of innovative silicone technologies for facade applications. One promising avenue is the development of hybrid materials, combining the strengths of silicone with other materials to further enhance weatherability (Ren et al., 2019).

However, despite the substantial body of evidence confirming the benefits of silicone for facade materials, further research is required. A more in-depth understanding of the chemical properties of silicone that contribute to weatherability, alongside an exploration of novel silicone technologies and a comprehensive assessment of their practical applications, would significantly enhance the field.

3. CHEMICAL PROPERTIES OF SILICONE

Silicones, also referred to as polysiloxanes, are polymeric materials characterized by a repeating Si-O backbone, where Si represents silicon and O represents oxygen (Li, 2023). Additionally, recent studies have highlighted the enhanced protective capabilities of silicone composites, such as those incorporating bismuth for radiation shielding, which further underscores the material's versatility (Mehnati et al., 2019). The silicon atoms are hybridized, leading to a tetrahedral arrangement, with two of the positions occupied by oxygen atoms and the remaining two by various organic groups, typically methyl groups (Urquiza, 2016). This unique structure and composition confer silicones with their distinct chemical properties, which, in turn, contribute to their weatherability when used in facade materials.

One of the critical properties that render silicones effective for weatherability is their UV stability. Unlike organic polymers that degrade under the influence of UV radiation, silicones possess a high degree of UV resistance due to their inorganic Si-O backbone (Chotprasert et al., 2022). Their molecular structure efficiently dissipates the energy absorbed from UV radiation, thereby preventing degradation (Zapciu et al., 2021). Moreover, silicones have the ability to shield the underlying materials from UV radiation, providing an additional layer of protection for the facade materials (Faxas-Guzmán, 2021).

Silicones also exhibit excellent thermal resistance. They can withstand extreme temperatures without losing their physical and chemical properties, a feature attributable to their strong Si-O bonds and low thermal conductivity (Soltys et al., 2023). This characteristic ensures that silicone-enhanced facade materials retain their integrity and performance even under fluctuating temperature conditions, a common scenario in many environmental contexts (Balakhnina & Borkowska, 2013).

Hydrophobicity is another inherent property of silicones that significantly contributes to the weatherability of facade materials. Due to the methyl groups attached to the silicon atoms, silicones naturally repel water (Andaloro et al., 2017). This property ensures that silicone-treated surfaces do not absorb water, effectively reducing moisture-related damage such as erosion, freeze-thaw cycles, and biological growth (Chen et al., 2021).

These inherent chemical properties UV stability, thermal resistance, and hydrophobicity make silicones particularly suitable for enhancing the weatherability of facade materials. By integrating silicones into these materials or applying them as coatings or sealants, one can significantly improve their resistance to environmental stressors, thereby enhancing their durability and lifespan (Bruno et al., 2017).

Table 1. Summary of Silicone's Chemical Properties

Property	Description	Impact on Weatherability
UV Stability	Silicones have a high degree of resistance to ultraviolet (UV) radiation due to their inorganic Si-O backbone.	Prevents degradation and shields underlying materials from UV damage.
Thermal Resistance	Silicones can withstand extreme temperatures without losing their physical and chemical properties.	Maintains integrity and performance under fluctuating temperature conditions.
Hydrophobicity	Silicones naturally repel water due to the methyl groups attached to the silicon atoms.	Reduces moisture-related damage such as erosion, freeze-thaw cycles, and biological growth.

Table 1: provides a summary of the key chemical properties of silicones that contribute to their effectiveness in enhancing the weatherability of facade materials.

Further research into these properties, alongside a more in-depth exploration of the specific mechanisms through which silicones impart weatherability, would significantly contribute to the development of advanced silicone-based technologies for facade materials. Such research could pave the way for novel applications and strategies that would maximize the advantages of silicones and ultimately contribute to more resilient and sustainable building practices.

4. ROLE OF SILICONE IN ENHANCING THE WEATHERABILITY OF FACADE MATERIALS

4.1 UV Radiation Resistance

Silicone's resistance to ultraviolet (UV) radiation is one of its most prominent attributes, having a profound impact on the durability of facade materials (Lim et al.,2020). The intrinsic chemical properties of silicones, particularly the strong Si-O bonds, enable them to absorb and dissipate UV energy, thus minimizing potential damage (Lopez-Garcia et al., 2021). This is a critical advantage over other organic polymers that may degrade under similar UV exposure, contributing to their overall weatherability. Figure 2 compares the UV stability of silicone with other common facade materials, highlighting the superior performance of silicone in resisting UV-induced degradation.

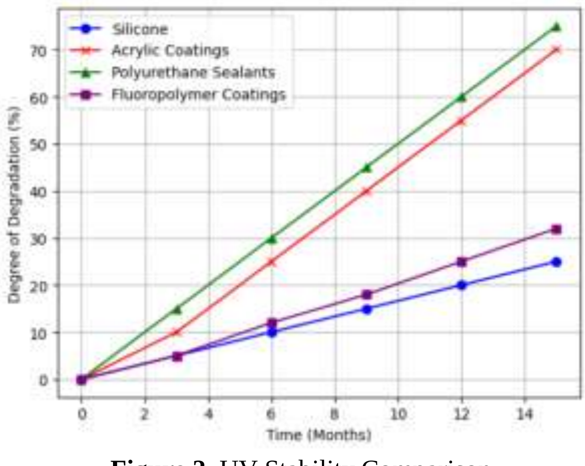

Figure 2. UV Stability Comparison

Source: *Adapted from Gagg et al. (2019) and Khan et al. (2020)*

Several studies have examined the UV-resistant properties of silicone. Lim et al. (2020) highlighted that silicone coatings significantly enhance the UV resistance of underlying materials, acting as a physical barrier against the harmful radiation. In practical applications, the use of silicone composites has expanded beyond traditional roles. For example, bismuth-silicone composites have been effectively used for radiation shielding, indicating potential for multifunctional facade applications (Mehnati et al., 2019). Moreover, silicone sealants have been found to remain unaffected by prolonged UV exposure, maintaining their elasticity and bonding strength (Wallau et al., 2021).

In practical applications, silicone's UV resistance has numerous benefits for facade materials. For instance, silicone-based coatings are widely used in the protection of heritage buildings, where the preservation of original materials is critical (Masson et al., 2022). Also, in modern construction, the use of silicone sealants aids in maintaining the aesthetic and structural integrity of facades despite harsh environmental conditions (Toniolo, & Lago, 2017). As such, the silicone's UV resistance is pivotal in enhancing the longevity and durability of facade materials.

4.2 Thermal Resistance

Silicone's resilience to temperature fluctuations significantly contributes to its value in facade materials. Due to its strong Si-O bonds and low thermal conductivity, silicone can withstand extreme temperature changes without substantial structural alterations (Binarti et al , 2020). This capacity to resist thermal degradation, while maintaining its physical and chemical properties, separates silicone from many other facade materials, ensuring its optimal performance under a variety of environmental conditions. Figure 3 illustrates the thermal resistance performance of silicone compared to other materials, showcasing its superior stability under various temperature conditions using a heat map.

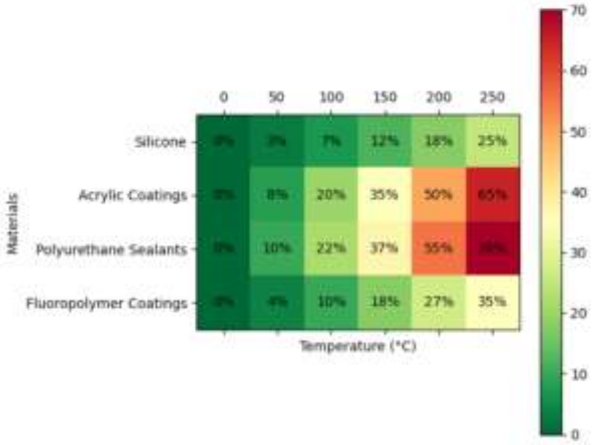

Figure 3: Thermal Resistance Performance Heat Map
Source: *Adapted from Lim et al. (2020) and Yamazaki et al. (2022)*

The resistance of silicone to temperature fluctuations significantly impacts the lifespan and integrity of facade materials. Silicone-based sealants and coatings retain their flexibility and adhesive properties even under wide temperature ranges, preventing facade materials from cracking and peeling (Lim et al., 2020). This thermally stable behavior of silicone provides a durable solution for maintaining facade integrity under weathering conditions, offering long-term protection against thermal stress (Yamazaki et al., 2022).

Evidence of this can be seen in case studies like those conducted by Humar et al. (2020), where silicone-impregnated facade materials showcased enhanced resistance to thermal cycling tests. Similarly, Sun et al. (2022) reported that the thermal resistance of silicone coatings contributed to the improved durability and longevity of facade materials in tropical climates. The thermal resistance of silicone, therefore, is a critical factor in its suitability for enhancing the weatherability of facade materials.

4.3 Hydrophobicity and Resistance to Precipitation

Silicone’s hydrophobic properties significantly contribute to its efficacy as a facade material, providing reliable resistance to moisture. Owing to its molecular structure, where methyl groups (-CH3) attached to silicon atoms interact minimally with water, silicone exhibits strong hydrophobic behavior (Leong et al., 2021). This inherent water-repellent quality of silicone aids in the protection of facade materials against precipitation such as rain, snow, and even high humidity environments. Figure 4 shows the results of hydrophobicity tests on silicone-treated materials, demonstrating their water-repellent properties compared to untreated and other treated materials.

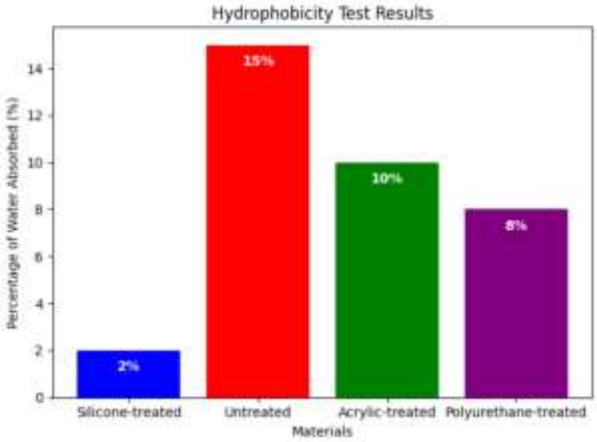

Figure 4: Hydrophobicity Test Results
Source: *Adapted from Hu et al. (2021) and Li et al. (2022).*

The ability of silicone to resist moisture penetration is a critical factor in the prevention of water-related damage to facade materials. By repelling water, silicone-based treatments reduce water absorption and the consequential risks of material degradation due to freeze-thaw cycles, efflorescence, and bio-deterioration (Asphaug et al., 2021). Hence, silicone contributes to enhancing the weatherability of facade materials, especially in regions exposed to regular or extreme precipitation.

Numerous studies confirm the efficiency of silicone as a hydrophobic agent for facade materials. For instance, research conducted by Vahabi et al. (2021) demonstrated how silicone-based coatings significantly reduced the water absorption rates in concrete facade materials, thus improving their durability. Similarly, a study by Hao et al. (2022) showed that silicone-treated brick facades demonstrated enhanced resistance to moisture-induced damages. Hence, the hydrophobic nature of silicone plays a pivotal role in fortifying facade materials against weathering caused by precipitation.

4.4 Different Silicone Products for Facade Materials

Several types of silicone products are used in enhancing the weatherability of facade materials, including silicone sealants and coatings. Silicone sealants are widely utilized due to their superior adhesion, flexibility, and durability, which are critical for weather sealing applications (Bontempi, 2021). These sealants effectively seal joints and gaps, thereby preventing water ingress and improving thermal efficiency. Table 2 provides a comparative analysis of different weathering enhancements, highlighting the effectiveness of silicone products compared to other materials.

Table 2. Comparative Analysis of Weathering Enhancements

Property	Silicone Sealants	Acrylic Coatings	Polyurethane Sealants	Fluoropolymer Coatings
UV Stability	Excellent	Moderate	Good	Excellent
Thermal Resistance	High	Moderate	Moderate	High
Hydrophobicity	High	Low	Moderate	High
Adhesion and Flexibility	Excellent	Moderate	Good	High
Longevity	Long-term	Short to Moderate	Moderate	Long-term
Cost	Moderate	Low	Moderate	High

Silicone-based coatings, on the other hand, provide a protective layer on the material's surface, enhancing UV resistance and hydrophobic properties (Amaechi, 2019). These coatings have been successfully used on various facade materials such as concrete, natural stone, and brickwork, where they have demonstrated significant improvement in weather resistance.

Comparatively, both silicone products serve different but complementary roles in enhancing the weatherability of facade materials. The choice between sealants and coatings largely depends on the specific requirements of the facade materials and the environmental conditions to which they are exposed.

Future developments in silicone products for facade materials focus on optimizing their protective properties and introducing additional functionalities. For example, research into self-cleaning silicone coatings is a promising avenue, offering potential advancements in the maintenance and longevity of facade materials (Çalışkan, & Arpacıoğlu, 2022).

5. CASE STUDIES

Silicone's remarkable weatherability properties have been practically utilized in various projects, and these case studies validate its effectiveness in enhancing the durability of facade materials. Further supporting this, recent developments in silicone composites for radiation shielding have demonstrated significant protective benefits, suggesting possible applications in enhancing facade materials' resilience against environmental factors (Mehnati et al., 2019).

One such case is the restoration of the historical Christ Church Cathedral in New Zealand, which suffered substantial damage during the 2011 earthquake (Bunyan et al., 2022). The construction team used silicone sealants to protect and weatherproof the new and existing stone facade. Despite the exposure to harsh climatic conditions, the silicone-protected facades demonstrated excellent resistance to moisture ingress and thermal degradation, verifying the long-term protection offered by silicone-based materials.

A study by Ferreira et al. (2021) investigated the performance of silicone coatings on concrete facades of buildings located in various climatic regions. The buildings coated with silicone exhibited significantly reduced surface degradation, moisture absorption, and efflorescence compared to non-coated ones, even after several years of exposure to the weather. This outcome underscores the long-term weatherability enhancements that silicone coatings confer on facade materials.

In another case, the Torre Agbar in Barcelona, known for its unique facade design comprising of aluminum and glass panels, used silicone sealants for panel bonding and weather sealing (Fragiacomo & Santarsiero, 2018). These sealants have effectively resisted the challenging Mediterranean climate, UV exposure, and temperature fluctuations, with the facade still retaining its aesthetic and functional quality years after construction.

Lastly, the use of self-cleaning silicone coatings on the facade of the Sino-Ocean Taikoo Li Chengdu shopping complex in China presents an intriguing case (Hu et al., 2020). The coatings' self-cleaning property has not only maintained the aesthetic appearance of the complex but also reduced maintenance costs, indicating the multifunctional benefits of advanced silicone products.

These case studies highlight the practical application of silicone products in diverse conditions and their success in enhancing the weatherability and longevity of facade materials. It is clear from these cases that silicone's inherent chemical properties, including UV stability, thermal resistance, and hydrophobicity, play a crucial role in its performance.

Table 3. Case Studies Overview

Project Name	Location	Application	Key Findings
Christ Church Cathedral Restoration	New Zealand	Silicone Sealant	Excellent resistance to moisture ingress and thermal degradation
Concrete Facade Coatings Study	Various regions	Silicone Coating	Reduced surface degradation, moisture absorption, and efflorescence
Torre Agbar	Barcelona, Spain	Silicone Sealants	Effective resistance to UV exposure and temperature fluctuations
Sino-Ocean Taikoo Li Chengdu	Chengdu, China	Self-cleaning Silicone Coatings	Maintained aesthetic appearance, reduced maintenance costs

6. INNOVATIVE SILICONE TECHNOLOGIES FOR FACADE MATERIALS

The continuous advancements in silicone technology are paving the way for more innovative and effective solutions in the construction industry, particularly in enhancing the weatherability of facade materials. Table 4 provides a summary of the key innovative silicone technologies discussed in this section, highlighting their specific applications and benefits.

Table 4. Summary of Innovative Silicone Technologies

Technology	Application	Benefits
Silicone-Organic Hybrid Materials (SOHMs)	Facade coatings and sealants	Superior UV resistance, thermal stability, flexibility
Silicone-PCM Coatings	Energy-efficient facades	Reduces heat transmission, lowers energy consumption
Self-Healing Silicone	Sealants and coatings	Automatic repair of minor damage, prolonged durability
Electroactive Silicone Materials	Smart building facades	Change properties (color, opacity) in response to electrical stimuli
Nano-Silicone Coatings	Facade coatings	Excellent hydrophobic properties, improved resistance to soiling and microbial growth, enhanced UV resistance

A significant development in this field is the advent of silicone-organic hybrid materials (SOHMs). Zhang et al (2016) highlighted that these hybrid materials combine the advantageous properties of both organic polymers and silicone, such as superior UV resistance, thermal stability, and flexibility. This synergy enhances the durability and weatherability of facade materials, making SOHMs a promising candidate for future applications.

In addition to enhancing weather resistance, silicone technology is also contributing to energy efficiency. The integration of phase change materials (PCMs) with silicone coatings is one such innovative approach. According to Zhang et al. (2022), the use of silicone-PCM coatings can effectively reduce heat transmission through the facade, thereby lowering energy consumption for heating and cooling. This innovation extends the scope of silicone's role in facade materials beyond weatherability, indicating its potential to contribute to sustainable construction practices (Kownacki et al., 2019).

Moreover, the development of self-healing silicone sealants and coatings presents another exciting technological advancement (Chaudhary & Kandasubramanian, 2022). These materials can automatically repair minor damage or wear, ensuring prolonged durability and maintaining the facade's protective capabilities without requiring frequent maintenance.

Silicone technology is also making strides towards smart buildings. The emerging field of electroactive silicone materials capable of changing properties (e.g., color, opacity) in response to electrical stimuli can revolutionize facade design and function (Ahmed et al., 2016). Such materials could adapt to changing weather conditions, thereby providing optimal weatherability and enhancing building occupants' comfort.

Lastly, nanotechnology is increasingly being incorporated in silicone products for facade applications. Nano-silicone coatings, for instance, offer excellent hydrophobic properties, improved resistance to soiling and microbial growth, and enhanced UV resistance (Li et al., 2022). These traits underscore the potential of nanotechnology in significantly improving the weatherability and longevity of facade materials.

The ongoing research and technological advancements in the field of silicone-enhanced facade materials underscore the potential for even more effective and multifunctional solutions in the future. As such, it is crucial for stakeholders in the construction industry to stay abreast of these innovations to optimize the weatherability and overall performance of building facades.

7. COMPARATIVE ANALYSIS OF SILICONE AND OTHER WEATHERING ENHANCEMENTS

Silicone-based enhancements are increasingly recognized for their ability to improve the weatherability of facade materials. However, it is beneficial to compare them with other common weathering enhancements to understand their relative effectiveness fully. Table 5 provides a comprehensive comparison of various weathering enhancements, highlighting their effectiveness in UV radiation resistance, thermal resistance, hydrophobicity, durability, and cost.

Table 5. Comparative Analysis of Weathering Enhancements

Enhancement Type	UV Radiation Resistance	Thermal Resistance	Hydrophobicity	Durability	Cost
Silicone	Superior	Exceptional	Excellent	High	Moderate
Acrylic Coatings	Good	Moderate	Moderate	Moderate	Low
Polyurethane	Good	Good	Moderate	Moderate	Moderate
Epoxy Coatings	Good	Moderate	Requires additives	High	Moderate
Fluoropolymer	Superior	Excellent	Excellent	Very High	High
PVC	Moderate	Moderate	Low	Low	Low

In terms of UV radiation resistance, silicone has proven to be superior to many other weathering enhancements such as acrylic coatings. A study by Ouali et al. (2019) found that while both silicone and acrylic coatings provided UV protection, silicone maintained better color stability and structural integrity after prolonged UV exposure.

When comparing thermal resistance, silicone demonstrates exceptional performance due to its broad operational temperature range. In contrast, materials like polyurethane, while also effective, have a narrower temperature range, thus limiting their applicability in extreme climatic conditions (Cui et al., 2022).

Silicone's hydrophobic nature endows it with excellent resistance to precipitation, surpassing that of many other treatments. For instance, epoxy coatings, despite their durability, do not inherently possess this quality, necessitating the addition of hydrophobic agents for similar performance (Gupta Bajpai, 2011).

The durability of silicone-based enhancements, specifically sealants and coatings, also exceeds that of comparable materials. Polyvinyl chloride (PVC) treatments, though cost-effective, tend to degrade faster under constant weather exposure compared to silicone (Zhou et al., 2021).

Nevertheless, silicone is not without competition. For instance, fluoropolymer-based coatings, owing to their excellent chemical stability and UV resistance, are often used in demanding architectural applications. However, they typically command a higher price point than silicone, making the latter a more cost-effective solution for many projects (Dobilaitė et al., 2020).

Finally, it is worth noting that combining silicone with other materials can further enhance its weatherability properties. For example, the integration of silicone and epoxy in hybrid coatings combines the superior UV resistance of silicone with the excellent mechanical strength of epoxy, resulting in a synergistic enhancement of facade durability (Zhao et al., 2020).

In conclusion, silicone-based enhancements, due to their unique properties and versatility, demonstrate a competitive edge over many common weathering enhancements. Ongoing research and technological advancements in the field promise further improvements in silicone's performance and application possibilities.

8. COST-BENEFIT ANALYSIS OF SILICONE APPLICATION IN FACADE MATERIALS

Economic implications are crucial factors in choosing building materials. Evaluating the cost-benefit analysis of using silicone-based enhancements for facade materials involves weighing initial application costs against potential long-term savings derived from increased longevity and decreased maintenance (Pérez et al., 2020). Table 6 provides a comparative analysis of the initial costs, maintenance costs, lifecycle costs, energy savings, and sustainability benefits of silicone-based enhancements compared to non-silicone counterparts.

Table 6. Cost-Benefit Analysis of Silicone vs. Non-Silicone Enhancements

Enhancement Type	Initial Costs	Maintenance Costs	Lifecycle Costs	Energy Savings	Sustainability Benefits
Silicone	High	Low	Low	High	Significant, potential LEED/BREEAM credits
Acrylic	Moderate	High	High	Moderate	Limited
Polyurethane	Moderate	Moderate	Moderate	Moderate	Moderate
Epoxy	Moderate	Moderate	Moderate	Low	Limited

Initial costs of silicone-based treatments, like coatings and sealants, are typically higher than their non-silicone counterparts due to the advanced manufacturing processes involved. However, these upfront costs are offset by the reduced frequency of applications necessitated by the superior weatherability of silicone. This enhanced durability results in longer replacement cycles, translating to significant cost savings over time (Davis et al., 2018).

Maintenance expenses, a critical aspect of the total cost of ownership, are also lower with silicone applications. Owing to their inherent resistance to environmental elements, silicone-enhanced facades require less frequent repairs and refurbishments. This reduction in maintenance efforts leads to considerable savings in labor and material costs, providing an economic advantage over conventional materials (Hassan et al., 2021).

A study by Hincapié et al. (2015) modeled the lifecycle costs of silicone and acrylic facade coatings over a 30-year period. Their findings revealed that despite higher upfront costs, the silicone coatings' long service life and lower maintenance costs resulted in a 20% decrease in total lifecycle costs compared to acrylic coatings.

Furthermore, silicone's superior performance under varying climatic conditions can also lead to savings in energy costs. By providing better insulation, silicone sealants and coatings help maintain indoor temperatures, reducing the demand for heating or cooling and thus contributing to energy efficiency (Oropeza-Perez, 2019).

The longevity of silicone also aligns with sustainable building practices, contributing to an overall reduction in environmental impacts and the potential for gaining credits under green building certification programs like LEED or BREEAM. This can increase a building's market value and attract tenants committed to sustainability (Andelin et al., 2015).

In summary, the economic implications of using silicone in facade materials extend beyond initial application costs. When considering the total lifecycle costs, including maintenance, repair, energy savings, and sustainability benefits, silicone-based enhancements present a compelling case for long-term cost-effectiveness.

9. ENVIRONMENTAL IMPACT AND SUSTAINABILITY

Assessing the environmental footprint of silicone in facade materials involves analyzing its life cycle: production, use, and end-of-life stages. While silicone's weatherability enhances facade longevity, its production, recycling, and disposal processes raise sustainability concerns (Tian et al., 2020).

Silicone's production process, heavily reliant on silicon metal, involves energy-intensive processes like quartz mining and carbon reduction (Kilian & Wiggers 2021). However, the industry is making strides towards reducing carbon emissions associated with these processes (Jin et al., 2017). Additionally, the longevity of silicone-treated facades reduces the frequency of material replacements, indirectly reducing the demand for new materials and associated production impacts (Attia et al., 2020).

In the use phase, silicone's durability and insulating properties help reduce energy consumption for heating and cooling, thereby decreasing the environmental impact over a building's lifetime (Zhang et al., 2017).

At the end-of-life stage, the issues of silicone recycling and disposal arise. Silicone's strong polymer structure, which provides its durability, is also what makes it challenging to recycle (Tembo et al., 2021). Current recycling methods include pyrolysis and glycolysis, which are still being optimized for efficiency and practicality (Lamberti et al., 2020). Some initiatives focus on designing silicone for easier recyclability, often termed "Design for Recycling" (DfR) (Mignacca & Locatelli, 2021).

Table 7. Environmental Impact of Silicone in Facade Materials

Lifecycle Stage	Environmental Impact	Sustainability Benefits	Challenges
Production	Energy-intensive processes, carbon emissions	Industry efforts to reduce emissions	High energy consumption, resource extraction
Use	Reduced energy consumption for heating/cooling	Improved energy efficiency, longer material lifespan	None significant
End-of-Life	Non-biodegradable, difficult to recycle	Inert, does not release hazardous compounds	Challenging recycling processes, non-biodegradable
Recycling/Disposal	Pyrolysis and glycolysis optimization needed, inert but non-biodegradable	Research into converting waste silicone into useful materials	Difficulties in efficient recycling, need for improved methods

When it comes to disposal, silicone is non-biodegradable. However, it is inert and does not release hazardous compounds into the environment, a quality advantageous over other non-biodegradable materials that might leach harmful substances (Tsang et al., 2015). Research is ongoing to develop methods for converting waste silicone into useful materials, such as activated carbon, to mitigate disposal issues (Tsai & Shih, 2014).

Overall, silicone's contribution to a building's environmental footprint is multifaceted. While it offers benefits in terms of durability and energy efficiency, its production and end-of-life management present sustainability challenges. With ongoing research and development, however, the industry aims to address these issues and increase the sustainability profile of silicone in facade applications. Table 7 provides a summary of the environmental impacts and sustainability aspects of silicone in facade materials across its lifecycle stages: production, use, and end-of-life.

10. IMPACT ON THE INDUSTRY

The application of silicone in facade materials is ushering a transformation in the construction industry, shifting it towards sustainability and improved durability (Leśniak & Górka, 2020). Silicone's weatherability can enhance the longevity of buildings, leading to less frequent replacements, which subsequently minimizes waste and conserves resources (Tabrizikahou et al., 2021).

Silicone-based materials not only result in longer-lasting structures but also reduce maintenance costs due to their resistance to UV light, temperature fluctuations, and corrosion (Moriot et al., 2017). This resistance improves building aesthetics over time and reduces the frequency of costly repairs, leading to considerable cost savings for property owners (Olanrewaju et al., 2018).

Furthermore, the durability of silicone-treated facades could redefine standards for building materials and construction practices. The industry may experience a shift toward more rigorous durability requirements and heightened emphasis on weatherability (Gholami & Røstvik, 2021). This shift could also spur further advancements in silicone technology and encourage other material innovations geared towards enhancing weatherability and durability (Singh & Agrahari, 2019).

In terms of business operations, the initial higher costs of silicone-based products could be offset by long-term savings from reduced maintenance and replacement expenses (Wagner & Ott, 2022). This economic viability may encourage more construction companies to adopt silicone-based products, fostering market growth for these materials (Ramesh & Reddy, 2017).

However, for these benefits to fully materialize, challenges related to silicone's recyclability and production processes must be addressed. The construction industry would benefit from collaborations with researchers, environmental organizations, and policymakers to develop effective solutions for these challenges (Namin et al., 2023).

To summarize, the use of silicone in facade materials has the potential to significantly change industry practices. While there are challenges to overcome, the benefits of longer-lasting structures and reduced maintenance costs could lead to a more sustainable and economically viable future for the construction industry.

11.FUTURE PERSPECTIVES

The horizon of silicone's role in facade materials is vast and promising. Future research will likely explore more innovative applications and silicone technologies that can enhance their performance and cost-effectiveness, whilst addressing environmental concerns. Strategies to improve the production processes and recyclability of silicone-based products could also be a significant area of focus, paving the way for a more circular economy in the construction industry. Additionally, breakthroughs in developing silicone variants with enhanced properties could usher in an exciting era in the construction industry.

12. CONCLUSIONS

Silicone has proven to be instrumental in enhancing the weatherability of facade materials, offering the industry a viable solution for durable and long-lasting structures. Its properties, such as superior UV stability, thermal resistance, and hydrophobicity, significantly improve resilience against environmental factors and reduce maintenance needs. These benefits are crucial in the face of climate change and increasing demands for sustainability.

The application of silicone-based products in facade materials leads to longer-lasting structures and reduced lifecycle costs. The initial higher costs of silicone-based treatments are offset by the extended lifespan of the materials and lower maintenance requirements. Additionally, silicone's excellent insulating properties contribute to energy efficiency, further enhancing its economic viability.

However, challenges remain, particularly regarding the production and recyclability of silicone. The production process is energy-intensive, and current recycling methods are not yet optimized for efficiency. Addressing these issues is imperative for maximizing the environmental benefits of silicone. Ongoing research and development efforts are crucial in this regard, aiming to reduce the carbon footprint of silicone production and improve recycling technologies.

Future perspectives for silicone in facade materials include the development of innovative technologies such as silicone-organic hybrids, phase change materials, and self-healing silicones. These advancements promise to further enhance the performance and sustainability of silicone-treated facades. The construction industry, researchers, and policymakers must collaborate to overcome existing challenges and leverage the full potential of silicone for sustainable building practices.

In conclusion, silicone's role in enhancing the weatherability of facade materials extends beyond material longevity to encompass economic efficiency and environmental responsibility. The continued evolution of silicone technologies will undoubtedly contribute to more resilient and sustainable construction practices in the future.

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References:

Ahmed, M. M. S., Abdel-Rahman, A. K., Bady, M., Mahrous, E., & Suzuki, M. (2016). Optimum Energy Consumption by Using Kinetic Shading System for Residential Buildings In Hot Arid Areas. *International Journal of Smart Grid and Clean Energy*, DOI: 10.12720/sgce.5.2.121-128.

Amaechi, B. T. (2019). Comparative Efficacy in Preventing Plaque Formation around Pit and Fissure Sealants: A Clinical Trial. *The Journal of Contemporary Dental Practice*, 5(20), 531-536. DOI: 10.5005/jp-journals-10024-2552.

Andaloro, A., Mazzucchelli, E. S., Lucchini, A., & Pedeferri, M. (2017). Photocatalytic Self-cleaning Coatings for Building Facade Maintenance. Performance Analysis Through a Case-study Application. *Journal of Facade Design and Engineering*, 3-4(4), 115-129. DOI: 10.3233/fde-160054

Andelin, M., Sarasoja, A., Ventovuori, T., & Junnila, S. (2015). Breaking the Circle of Blame for Sustainable Buildings – Evidence From Nordic Countries. *Journal of Corporate Real Estate*, 1(17), 26-45. DOI: 10.1108/jcre-05-2014-0013.

Asphaug, S. K., Time, B., & Kvande, T. (2021). Moisture Accumulation In Building Façades Exposed To Accelerated Artificial Climatic Ageing—a Complementary Analysis To Nt Build 495. *Buildings*, 12(11), 568. DOI: 10.3390/buildings11120568.

Attia, S., Lioure, R., & Declaude, Q. (2020). Future Trends and Main Concepts of Adaptive Facade Systems. *Energy Science & Engineering*, 9(8), 3255-3272. DOI: 10.1002/ese3.725.

Balakhnina, T. I., & Borkowska, A. (2013). Effects of Silicon On Plant Resistance To Environmental Stresses: Review. *International Agrophysics*, 2(27), 225-232. DOI: 10.2478/v10247-012-0089-4

Biloria, N., Makki, M., & Abdollahzadeh, N. (2023). Multi-performative Façade Systems: the Case of Real-time Adaptive Bipv Shading Systems to Enhance Energy Generation Potential and Visual Comfort. *Frontiers in Built Environment*, (9), DOI: 10.3389/fbuil.2023.1119696 .

Binarti, F., Pranowo, P., & Leksono, S. M. (2020). Microclimate Models to Predict the Contribution of Facade Materials to The Canopy Layer Heat Island In Hot-humid Areas. *Geographia Technica*, 42-52. DOI: 10.21163/gt_2020.151.21.

Blocken, B. B., Derome, D., & Carmeliet, J. (2013). Rainwater Runoff from Building Facades: a Review. *Building and Environment*, (60), 339-361. DOI: 10.1016/j.buildenv.2012.10.008.

Bollmann, U. E., Minelgaite, G., Schlüsener, M. P., Ternes, T. A., Vollertsen, J., & Bester, K. (2017). Photodegradation of Octylisothiazolinone and Semi-field Emissions from Facade Coatings. *Scientific Reports*, 1(7), DOI: 10.1038/srep41501.

Bontempi, E., Sorrentino, G. P., Zanoletti, A., Alessandri, I., Depero, L. E., & Caneschi, A. (2021). Sustainable Materials and Their Contribution to the Sustainable Development Goals (Sdgs): A Critical Review Based On An Italian Example. *Molecules*, 5(26), 1407. DOI: 10.3390/molecules26051407

Bruno, A. W., Gallipoli, D., Perlot, C., & Mendes, J. (2017). Effect of Stabilisation on Mechanical Properties, Moisture Buffering and Water Durability of Hypercompacted Earth. *Construction and Building Materials*, (149), 733-740. DOI: 10.1016/j.conbuildmat.2017.05.182.

Bunyan, S. F., Suhaimi, F. M., Zardawi, F. M., Noor, S. N. F. M., & Zabidi, M. A. (2022). Enhancement of Tech-sil25 Maxillofacial Silicone Mechanical Properties After Artificial Weathering Through Addition of Nanoparticles. *International Journal of Dentistry*, (2022), 1-9. DOI: 10.1155/2022/4082168

Çalışkan, C., & Arpacıoğlu, Ü. (2022). Additive Manufacturing On the Façade: Functional Use of Direct Metal Laser Sintering Hatch Distance Process Parameters in Building Envelope. *Rapid Prototyping Journal*, 9(28), 1808-1820. DOI: 10.1108/rpj-11-2021-0300.

Chaudhary, K., & Kandasubramanian, B. (2022). Self-healing Nanofibers for Engineering Applications. *Industrial & Engineering Chemistry Research*, 11(61), 3789-3816. DOI: 10.1021/acs.iecr.1c04602

Chen, S., Ren, J., Li, Y., Ren, X., Song, Y., & Sun, J. (2021). Macroscopic and Mesoscopic Deterioration Behaviors Of Concrete Under The Coupling Effect Of Chlorine Salt Erosion And Freezing–thawing Cycle. *Materials*, 21(14), 6471. DOI: 10.3390/ma14216471.

Chen, X., Li, C., & Tsang, H. K. (2009). Grating Coupler for Mid-infrared Silicon-on-sapphire Waveguide. 2009 14th OptoElectronics and Communications Conference. 2009 14th OptoElectronics and Communications Conference (p. DOI: 10.1109/oecc.2009.5222623). Hong Kong, China: IEEE.

Chotprasert, N., Shrestha, B., & Sipiyaruk, K. (2022). Effects Of Disinfection Methods On the Color Stability Of Precolored And Hand-colored Maxillofacial Silicone: An in Vitro Study. *International Journal of Biomaterials*, (2022), 1-5. DOI: 10.1155/2022/7744744

Cui, H., Jing, Q., Li, D., Zhuang, T., Gao, Y., & Ran, X. (2022). Study On the High-temperature Damping Properties Of Silicone Rubber Modified By Boron-terminated Polysiloxane. *Journal of Applied Polymer Science*, 1(140), DOI: 10.1002/app.53262.

Davis, A., Surdo, S., Caputo, G., & Athanassiou, A. (2018). Environmentally Benign Production of Stretchable and Robust Superhydrophobic Silicone Monoliths. *ACS Applied Materials & Interfaces*, 3(10), 2907-2917. DOI: 10.1021/acsami.7b15088.

Dobilaitė, V., Jucienė, M., Bliūdžius, R., & Šveikauskaitė, L. (2020). Investigation Of Some Weathering Impacts On Tearing Properties Of Pvc-coated Fabrics Used for Architectural Purposes. *Journal of Industrial Textiles*, 3(51), 5328S-5346S. DOI: 10.1177/1528083720982384

Eleftheriadis, G., & Hamdy, M. (2018). The Impact of Insulation and HVAC Degradation on Overall Building Energy Performance: A Case Study. *Buildings*, 8(2), 23. DOI: 10.3390/buildings8020023.

Faxas-Guzmán, J., Ferreira, J., González, V., Guerrero, N., Guerrero, N., & Ramirez, F. C. (2021). Thermal Performance Of Facades Based On Experimental Monitoring Of Outdoor Test Cells In Tropical Climate. *Civil Engineering Journal*, 12(7), 1982-1997. DOI: 10.28991/cej-2021-03091773.

Ferreira, C., Barrelas, J., Silva, A., de Brito, J., Dias, I. S., & Flores-Colen, I. (2021). Impact of Environmental Exposure Conditions on the Maintenance of Facades' Claddings. *Buildings*, 11(4), 138. DOI: 10.3390/buildings11040138.

Fragiacomo, M., & Santarsiero, M. (2018). Transparency Iin Structural Glass Systems via Mechanical, Adhesive, and Laminated Connections - Existing Research and Developments. *Advanced Engineering Materials*, 5(20), 1700815. DOI: 10.1002/adem.201700815.

Gholami, H., & Røstvik, H. (2021). Dataset for the Solar Incident Radiation and Electricity Production Bipv/bapv System On The Northern/southern Façade In Dense Urban Areas. *Data*, 6(6), 57. DOI: 10.3390/data6060057.

Gomes, N. F., Rodrigues, T. B., Santos, K. L. d., Celso, F., Vuorio, T., & Jahno, V. D. (2022). Natural Weathering Of Composites Developed From Cellulose Waste and Post-consumer Paper. *Brazilian Journal of Environmental Sciences*, 3(57), 491-504. DOI: 10.5327/z2176-94781350.

Gupta, P. K., & Bajpai, M. (2011). Development of Siliconized Epoxy Resins and Their Application as Anticorrosive Coatings. *Advances in Chemical Engineering and Science*, 03(01), 133-139. DOI: 10.4236/aces.2011.13020.

Han, X., Zheng, K., Zhang, Y., Zhang, X., Zhang, Z., & Wang, Z. L. (2007). Low-temperature In Situ Large-strain Plasticity Of Silicon Nanowires. Advanced Materials, 16(19), 2112-2118. DOI: 10.1002/adma.200602705

Hao, J., Yu, L., Cui, Y., Wan, W., & Huang, J. (2021). Novel Micron-thick Brick Cladding of Polyfluorosilicone Acrylates, a Case Study of Conservation of Historic Brick Wall in Hongcun Village. *RSC Advances*, 28(11), 17399-17407. DOI: 10.1039/d0ra10434e.

Hassan, M. S., Attia, M., & Attia, R. M. (2021). Improving of Thermal Stability and Water Repellency of Cotton Fabrics Via Coating With Silicone Rubber Under The Effect Of Electron Beam Irradiation. *Journal of Industrial Textiles*, 3(51), 4899S-4912S. DOI: 10.1177/15280837211046622.

Hincapié, I., Künniger, T., Hischier, R., Cervellati, D., Nowack, B., & Som, C. (2015). Nanoparticles in Facade Coatings: a Survey Of Industrial Experts On Functional And Environmental Benefits And Challenges. *Journal of Nanoparticle Research*, 7(17), DOI: 10.1007/s11051-015-3085-3

Htet, A., Liana, S.R., Aung, T., & Bhaumik, A. (2023). Economic and Environmental Impact Analysis of Green Building Materials in Facade Engineering. *International Journal of Membrane Science and Technology*, 10(2). 2805-2814. DOI: 10.15379/ijmst.v10i2.2973.

Hu, C., He, G., Chen, J., Fang, Z., Yang, Z., & Zhang, Z. (2020). Research On Cleaning Mechanism Of Anti-erosion Coating Based On Thermal and Force Effects Of Laser Shock. *Coatings*, 7(10), 683. DOI: 10.3390/coatings10070683.

Humar, M., Lesar, B., & Kržišnik, D. (2020). Moisture Performance Of Façade Elements Made Of Thermally Modified Norway Spruce Wood. *Forests*, 3(11), 348. DOI: 10.3390/f11030348.

Jin, L., Duan, K., Shi, C., & Ju, X. (2017). The Impact of Technological Progress in the Energy Sector on Carbon Emissions: An Empirical Analysis From China. *International Journal of Environmental Research and Public Health*, 12(14), 1505. DOI: 10.3390/ijerph14121505

Kilian, S., & Wiggers, H. (2021). Gas-phase Synthesis of Silicon-rich Silicon Nitride Nanoparticles for High Performance Lithium–ion Batteries. *Particle & Particle Systems Characterization*, 4(38), 2100007. DOI: 10.1002/ppsc.202100007.

Kownacki, K. L., Gao, C., Kuklane, K., & Wierzbicka, A. (2019). Heat Stress in Indoor Environments of Scandinavian Urban Areas: a Literature Review. *International Journal of Environmental Research and Public Health*, 4(16), 560. DOI: 10.3390/ijerph16040560

Lamberti, F., Román-Ramírez, L., & Wood, J. (2020). Recycling Of Bioplastics: Routes and Benefits. *Journal of Polymers and the Environment*, 10(28), 2551-2571. DOI: 10.1007/s10924-020-01795-8.

Leong, G. W., Chua, H. L., Alengaram, U. J., Ibrahim, Z., & Loh, Z. H. (2021). Comparative Study of Lightweight Cementitious Composite Reinforced With Different Fibre Types and The Effect Of Silane-based Admixture. *Advances in Civil Engineering*,(2021), 1-10. DOI: 10.1155/2021/2190813

Leśniak, A., & Górka, M. (2020). Structural Analysis of Factors Influencing the Costs of Facade System Implementation. *Applied Sciences*, 17(10), 6021. DOI: 10.3390/app10176021

Li, Q., Liang, H., Song, J., Guo, C., & Tang, J. (2022). Preparation of Transparent Sandwich-like Superhydrophobic Coating on Glass with High Stability and Self-cleaning Properties. *Coatings*, 2(12), 228. DOI: 10.3390/coatings12020228.

Li, Y. (2023). Preparation method and application of silicon nanowires. Highlights in Science, Engineering and Technology, 32, 237–244. DOI: 10.54097/hset.v32i.5172.

Lim, C., Liu, J., Jiao, X., Cheng, F., Lai, G., & Yang, X. (2020). Uv-cured Transparent Flexible Silicone Materials with High Tensile Strength. *ACS Omega*, 11(5), 6199-6206. DOI: 10.1021/acsomega.0c00401

Lopez-Garcia, A. J., Blázquez, O., Voz, C., Puigdollers, J., Izquierdo-Roca, V., & Pérez-Rodríguez, A. (2021). Ultrathin Wide-bandgap A-si:h-based Solar Cells For Transparent Photovoltaic Applications. *Solar RRL*, 1(6), 2100909. DOI: 10.1002/solr.202100909.

Masson, J., Collins, P. L., Riahinezhad, M., Lopez-Carreon, M. I., & Johansen, J. J. (2022). Resistance of a Silicone Membrane To Long-term Uv And Moisture Aging In Light Of Climate Change. *Canadian Journal of Civil Engineering*, 2(49), 192-200. DOI: 10.1139/cjce-2020-0730.

Mehnati, P., Arash, M., Zakerhamidi, M. S., & Ghavami, M. (2019). Designing and construction of breast shields using silicone composite of Bismuth for chest CT. *International Journal of Radiation Research*, 17(3), 499-504.

Mignacca, B., & Locatelli, G. . (2021). Modular Circular Economy in Energy Infrastructure Projects: Enabling Factors and Barriers. *Journal of Management in Engineering*, 5(37), DOI: 10.1061/(asce)me.1943-5479.0000949 .

Moriot, J., Quaegebeur, N., Duff, A., & Masson, P. . (2017). A Model-based Approach for Statistical Assessment of Detection and Localization Performance Of Guided Wave–based Imaging Techniques. *Structural Health Monitoring*, 6(17), 1460-1472. DOI: 10.1177/1475921717744679

Namin, P., Booth, P., Silva, J., Voigt, L., & Zelisko, P. (2023). Transparent and Thermoplastic Silicone Materials Based On Room-temperature Diels–alder Reactions. *Macromolecules*, 5(56), 2038-2051. DOI: 10.1021/acs.macromol.2c00890.

Okokpujie, I. P., Essien, V., Ikumapayi, O. M., Nnochiri, E. S., Okokpujie, K., & Akinlabi, E. T. . (2022). An Overview Of Thermal Insulation Material For Sustainable Engineering Building Application. *International journal of design & nature and ecodynamics*, 6(17), 831-841. DOI: 10.18280/ijdne.170603.

Olanrewaju, A., Fang, W., & Tan, S. . (2018). Hospital Building Maintenance Management Model. *International Journal of Engineering & Technology*, 2.29(7), 747. DOI: 10.14419/ijet.v7i2.29.14010.

Oropeza-Perez, I. (2019). The Influence of an Integrated Driving On the Performance of Different Passive Heating and Cooling Methods For Buildings. *Buildings*, 11(9), 224. DOI: 10.3390/buildings9110224

Ouali, S., Germain, P., Gourdon, R., Desjardin, V., & Louis, Y. (2019). Monitoring Of Abiotic Degradation of Photocrosslinked Silicone Acrylate Coatings: the Fate of The Photoinitiator. *Environmental Science and Pollution Research*, 15(26), 15324-15332. DOI: 10.1007/s11356-019-04937-1.

Pérez, I. A., García, M. B., Sánchez, M. P. B., Pardo, N., & Fernández-Duque, B. (2020). Key Points in Air Pollution Meteorology. *International Journal of Environmental Research and Public Health*, 22(17), 8349. DOI: 10.3390/ijerph17228349.

Pizzatto, S. M. d. S., Pizzatto, F. O., Angioletto, E., Alves, A. K., Junca, E., & Montedo, O. R. K. (2021). Thermal Evaluation of the Use of Porous Ceramic Plates on Ventilated Façades—part II: Thermal Behavior. *International Journal of Applied Ceramic Technology*, 5(18), 1734-1742. DOI: 10.1111/ijac.13781

Ramesh, R., & Reddy, D. (2017). Quest for Novel Chemical Entities through Incorporation of Silicon in Drug Scaffolds. *Journal of Medicinal Chemistry*, 9(61), 3779-3798. DOI: 10.1021/acs.jmedchem.7b00718.

Ren, X., Li, J., Hu, M., Pei, G., Jiao, D., Zhao, X., & Ji, J. (2019). Feasibility of an Innovative Amorphous Silicon Photovoltaic/thermal System for Medium Temperature Applications. *Applied Energy*, (252), DOI: 10.1016/j.apenergy.2019.113427

Sangermano, M., Razza, N., & Crivello, J. V. (2014). Cationic Uv-curing: Technology and Applications. Macromol. Mater. *Macromolecular Materials and Engineering*, 7(299), 775-793. DOI: 10.1002/mame.201300349.

Singh, J., & Agrahari, A. (2019). The Progression Of Silicon Technology Acting As Substratum For the Betterment Of Future Photovoltaics. *International Journal of Energy Research*, 9(43), 3959-3980. DOI: 10.1002/er.4402

Soltys, L., Mironyuk, I., Mykytyn, I., Hnylytsia, I., & Turovska, L. (2023). Synthesis and Properties of Silicon Carbide. *Physics and Chemistry of Solid State*, 24(1), 5-16. DOI: 10.15330/pcss.24.1.5-16.

Subramani, S., Jaisankar, S. N., C, S., & Mary, N. (2018). Mechanical, Dielectric, and Thermal Properties of Polydimethylsiloxane/polysilsesquioxane Nanocomposite for Sealant Application. *Journal of Applied Polymer Science*, 12(136), 47228. DOI: 10.1002/app.47228.

Sun, C., Wang, D., Xu, C., Chen, W., & Zhang, Z. (2022). Comparative study on polysilazane and silicone resins as high-temperature-resistant coatings. *High Performance Polymers*, 34(4), 474-486. DOI: 10.1177/09540083211069041.

Švajlenka, J., & Kozlovská, M. (2018). Houses Based on Wood as an Ecological and Sustainable Housing AlternativeCase Study. *Sustainability*, 10(5), 1502. DOI: 10.3390/su10051502

Tabrizikahou, A., Kuczma, M., Nowotarski, P., Kwiatek, M., & Javanmardi, A. (2021). Sustainability of Civil Structures Through the Application Of Smart Materials: *A Review. Materials*, 17(14), 4824. DOI: 10.3390/ma14174824.

Tembo, P., Heninger, M., & Subramanian, V. (2021). An Investigation Of the Recovery Of Silicon Photovoltaic Cells By Application Of An Organic Solvent Method. *ECS Journal of Solid State Science and Technology*, 2(10), 025001. DOI: 10.1149/2162-8777/abe093

Tian, X., Stranks, S. D., & You, F. (2020). Life Cycle Energy Use and Environmental Implications of High-performance Perovskite Tandem Solar Cells. *Science Advances*, 31(6), DOI: 10.1126/sciadv.abb0055.

Tobin, Z., Petroski, K., Kerns, P., Almansour, A. S., Grady, J. E., & Suib, S. L. (2020). Focused Ion Beam-prepared Transmission Electron Microscopy Examination Of Atmospheric Chemical Vapor-infiltrated Silicon Carbide Morphology. *ACS Omega*, 1(6), 863-870. DOI: 10.1021/acsomega.0c05442.

Toniolo, G., & Lago, B. D. (2017). Conceptual Design and Full-scale Experimentation of Cladding Panel Connection Systems Of Precast Buildings. *Earthquake Engineering & Structural Dynamics*, 14(46), 2565-2586. DOI: 10.1002/eqe.2918.

Tsai, T., & Shih, Y. (2014). Recovery of Polyalkylene Glycol from Silicon Cutting Waste Using Centrifugation. *Desalination and Water Treatment*, 2(56), 443-451. DOI: 10.1080/19443994.2014.936518.

Tsang, M., Sonnemann, G., & Bassani, D. (2015). A Comparative Human Health, Ecotoxicity, and Product Environmental Assessment on the Production of Organic And Silicon Solar Cells. *Progress in Photovoltaics*, 5(24), 645-655. DOI: 10.1002/pip.2704.

Urquiza, M. L. (2016). First-principles Studies of Silicon Underpotential Deposition on Defective Graphene and Its Relevance for Lithium-ion Battery Materials. *Electrochimica Acta*, (208), (208), 92-101. DOI: 10.1016/j.electacta.2016.05.001.

Vahabi, M. Y., Tahmouresi, B., Mosavi, H., & Aval, S. F. . (2021). Effect of Pre-coating Lightweight Aggregates on the Self-compacting Concrete. *Structural Concrete*, 4(23), 2120-2131. DOI: 10.1002/suco.202000744.

Wagner, D., & Ott, S. . (2022). Cascading Wood-based Construction Products – a Guideline for Product Development. E3s Web of Conferences, (349), 04009. DOI: 10.1051/e3sconf/202234904009.

Wallau, W., Recknagel, C., & Smales, G. J. (2021). Structural Silicone Sealants after Exposure to Laboratory Test For Durability Assessment. *Journal of Applied Polymer Science Journal of Applied Polymer Science*, 35(138), 50881. DOI: 10.1002/app.50881.

Yamazaki, R., Ozaki, K., Imaizumi, T., Yamamoto, S., & Ushio, Y. (2022). Novel Silicone Hotmelt Adhesive For Display Assembly Applications. S*ID Symposium Digest of Technical Papers*, 1(53), 447-449. DOI: 10.1002/sdtp.15518 .

Zapciu, A., Baciu, F., Baciu, F., Vasile, M., & Popescu, D. (2021). Aging Of 3d Printed Polymers under Sterilizing Uv-c Radiation. *Polymers*, 24(13), 4467. DOI: 10.3390/polym13244467 .

Zhang, L., Gustavsen, A., Jelle, B. P., Gao, T., & Wang, Y. (2017). Thermal Conductivity of Cement Stabilized Earth Blocks. *Construction and Building Materials*, (151), 504-511. DOI: 10.1016/j.conbuildmat.2017.06.047

Zhang, Z., Nguyen, H. T. H., Miller, S. D., Ploskonka, A. M., DeCoste, J. B., & Cohen, S. M. . (2016). Polymer–metal–organic Frameworks (Polymofs) As Water Tolerant Materials for Selective Carbon Dioxide Separations. *Journal of the American Chemical Society*, 3(138), 920-925. DOI: 10.1021/jacs.5b11034.

Zhao, R., Zhang, Z., & Qi, Y. (2020). Influence of Epoxy Content On the Properties And Marine Bacterial Adhesion Of Epoxy Modified Silicone Coatings. C*oatings*, 2(10), 126. DOI: 10.3390/coatings10020126.

Zhou, Z., Song, Q., Huang, B., Feng, S., & Lu, C. (2021). Facile Fabrication of Densely Packed Ti3c2 Mxene/nanocellulose Composite Films For Enhancing Electromagnetic Interference Shielding and Electro-/photothermal Performance. *ACS Nano*, 7(15), 12405-12417. DOI: 10.1021/acsnano.1c04526

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