Solving Structural Degradation and Reducing Financial Risk in Masonry via Nano-Silane Based Polymer Nanocoatings

Masonry protection using nano-silane based polymers can minimize aging effects and produce huge savings for individual home owners, public buildings and campus properties

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Abstract

Water intrusion in porous construction materials, including concrete, brick, stucco, and cement/cement board accelerates structural degradation, bio-deterioration, and premature material failure. Treatments and sealers on the market today are susceptible to weathering and require frequent reapplication. This paper introduces an innovative, semi-inorganic organosilane sol-gel nanocoating technology that penetrates porous substrates to form a durable, three-dimensional inorganic network from the inside out. This technology offers superior breathability, water-repellency, and long-term protection against environmental degradation in structural masonry and cement-based composites. The additional benefits include significant elimination of microbial; from bacterial, fungal and spore based natural threats during the lifetime of phase

changes in masonry. Beyond the technology, this paper examines the broad economic impacts and implications of structural maintenance, particularly within the context of Homeowners Associations (HOAs) and commercial buildings while briefly examines the impact to pipelines that are used in municipalities and include deep well drill structures.

Introduction

Water invasion into porous construction materials (e.g., natural stones, concrete, grout, stucco, drywall, plaster, wood, wood-based composites, etc.) is the leading cause of accelerated structural degradation and ultimately premature material failure, often leading to exorbitant remediation costs. Surface treatments are regarded as a cost-effective way to combat water invasion as most forms of degradation primarily start at the surface prior to incursion/filtrating further into the bulk of the material. Apart from the functionality of a given surface treatment, an equally important aspect in developing a robust functional coating that can withstand perennial solar and environmental detriments is the underlying composition of the coatings itself (i.e., the host matrix), enabling it that can withstand perennial environmental attacks. The active structural components in the vast majority of commercially available coatings and sealers today are primarily organic in chemical composition (i.e., carbon-based systems). Such systems typically implement various forms and/or combinations of polyester-, polyurethane-, epoxy-, latex-, or acrylic-based polymers, all of which are largely archaic in application. While they have a huge array of uses, organic polymers, oligomers, dimers are highly susceptible to degradation, predominantly in exterior applications, where direct exposure to sunlight, and other weathering elements are prevalent [1].

After over a decade of research and suitable patents granted, aseries of nano-coating technologies based on organosilane sol-gel chemistry designed to impart water-/weather-proofing properties to a wide range of porous and non-porous materials has been developed and coined the name Self-Cleaning Hydrophobic Nano coatings, or SCHN coatings. For porous materials, the SCHN coatings are rooted in a sophisticated bottom-up molecular system that, in effect, forms a tailorable protective interpenetrating inorganic network that seeps into a material to form a nano-/-micro-structured barrier from the inside out. This hydrophobic barrier was originally designed to lock desired functionalities/properties in while concomitantly equally diminishing thwarting the effects of environmental elements detrimental to the integrity of otherwise untreated host materials. In doing so, this also accommodates the option of imparting a variety of selective functionalities to the bulk and surfaces of certain substrates that such materials fail to ordinarily or intrinsically exhibit, including mold/mildew resistance.

Two fundamental facets comprise the cornerstone of this technology, which holistically differentiates us from other existing technologies: 1.) The mechanism by which the coatings protect a given host material; 2.) The ability of the chemistry involved to function as a penetrating delivery system for an assortment of additional functional additives (e.g., IR-reflectants, biocides, flame-retardants, UV stabilizers, etc.). In contrast to the vast majority of polymeric coatings, this molecular system percolates through porous materials while intimately interacting with the molecular structure of a suitable host/substrate material to form a three-dimensional protective barricade against the elements. This is functionally different from conventional sealers, lacquers, varnishes, enamels, or glosses that merely form an easily erodible surface coating. As a result of the robust encapsulation mechanism underlying this core platform the SCHN coatings are also proficient at extending the useful life of various elements/additives construction/building materials while concurrently reducing the frequency of coating reapplication, mitigating the costly tax- dollar and time- consequence repercussions typically associated with conventional alternatives.

Concrete remains the most ubiquitous construction material in the United States, forming the bulk of most structures in urban areas and the highways, roads, and bridges that connect them [2,3]. The weathering and subsequent degradation of 30% of all porous construction materials, including concrete, is attributed to biodeterioration [4,5]. Biodeterioration herein refers to the degradation of a material through the actions of microorganisms, including but not limited to water intrusion, mold, mildew, algae, lichen, bacteria, and protozoa. In addition to aesthetic defacement of exposed surfaces, these microorganisms are known to degrade concrete through either the excretion of metabolic intermediates, end-products (e.g., organic acids), and/or exoenzymes [6,2]. Irrespective of the mechanisms of action, essentially all of these microorganisms require water as a key nutrient for survival, rendering aquatic/marine regions or regions of high relative humidity (>70%) and moderate temperature (5 – 35 ºC) most susceptible. As a result, the more porous the material, the more conducive it is to microbial colonization.

Alternative Technologies

The 20th Century Technology

Starting in the 1950s, hundreds of manufacturing and industrial applications relied on surfactant-based, fluorocarbon chemistry to create fluoropolymers—substances with special properties, such as hydrophobicity and oleophobicity. Surfactant-based, fluorocarbon chemistry involves molecules that join carbon and fluorine with a surfactant, or a soap molecule, to allow the molecule to become very soluble in water. These molecules bind very well with substrate surfaces to form fantastic hydrophobic barriers—both for water and oil-based systems. Unfortunately, when these molecules break down and inevitably leach out, given their solubility in water, there is no effective way to remove them from the ecosystem. Consequently, the small fluorocarbon molecules (such as PFOS or PFOA) that result from the breakdown of fluoropolymers find their way into mammals and humans alike through bioaccumulation. Accumulation of the molecules in the body occurs because mammalian livers cannot break down these harmful molecules, which leads to a potentially ever-increasing toxicity. It has been estimated that 95% of adults in the US now have this surfactant fluorocarbons accumulated in their bodies at a variety of concentrations.

Environmental regulators in the US, Japan, and Europe, increasingly concerned about the toxicity of these PFOA and PFOS molecules, began seeking to reduce the use and production of these molecules by the chemical industry. In response to the reduction efforts of government agencies, the chemical industry began developing alternatives to PFAS per- and polyfluoroalkyl substances (to which PFOS- and PFOA-based technologies belong).This list of companies include but not limited to AGC, Arkema, Chemours, Daikin, 3M, Solvay, Dongyue, Archroma, Merck, Bayer, BASF and Honeywell.

Alternative Non-Fluorocarbon Solutions

In response to the need for effective waterproof coatings, smaller coating companies are pursuing alternative competing technologies, which can be classified into general classes described in more detail below.

Plasma treatment – Surfaces can become 'activated' or to put in a simpler way, given a charge just like we find when running on carpet and then touching a handle. That 'shock' is something that is used to bring a surface into alignment to allow bonding to occur. However, this has limited appeal due to the high energy requirement to generate plasmas, the difficulty in controlling the application method, and limited scalability to larger mass production settings. Recent efforts were put into N95 masks with the idea of a charged surface being a way to catch covid particles. The truth is that these charges are not a form of energy storage and will dissipate shortly as such static effects have a very limited shelf. If that were not the case, we would all be using static discharge to power up our cell phone to providing 'clean energy storage' which it is not!

Silicones – Think about glass beads and we have silicone gels and the gel part being the viscous carrier solution as the vehicle. However, glass is notorious for not providing a good surface for binding, just think of glass ware in a chemistry lab or even used in bars to understand just how unhelpful these beads are.

Organic polymers – Plastics are an alternative to fluorocarbons, and for the last decade many researchers have looked towards plastics as the ideal solution. In this situation it's easier to refer to the word plastics rather than whole host of organic molecules that include, polymers, oligomers, trimers to monomers, large organic or organometallic centric maters to the whole new world of Fullerenes. There are problems with organic based only solutions, even C_{60} the grandfather of all fullerenes oxidizes easily. The biggest reason for this is that such research is a costly affair, requires highly qualified PhD's and senior masters level trained researchers. So, industry has fallen into the trap of waiting for a university to deliver a solution rather than have a significant research centric focus, as was once the case in Allied Signal out of New Jersey or Kodiak from upstate NY.

Other waterproof solutions – Barrier protection layers from epoxy or polyurethane chemistry-based coatings are well known and are in themselves a huge problem. They have the drawback of using epoxy coatings on garages and driveways that include a film-forming texture (paint-like finish), which are extremely slippery when wet or in contact with oil/grease. Other problems include wear and tear as visible areas of wear progressively worsen as tire tracks gouge into the epoxy. They cost a fortune to replace and clean up, which is why once they are used, are not ever touched again because of the cost involved.

But what does this mean for the real world and practical innovations? The SCHN series of coatings are demonstrating that big budgets are not needed, but education and innovation and from fresh student minds thinking why now. Let’s explore what nanotech can bring to the real world.

Where Technology Can Make a Difference

There are going to be three big purchases in everyone's life that cost more than a monthly salary and potentially more than a single year of net savings. They are college, cars, and home—one of which loses all value eventually, your car.

Going to college requires a huge investment in time; the return is only seen after some years, with the understanding that there is a continuous requirement of up-skilling to keep pace with our progressive lives. Purchasing a car is not just down to negotiating a price in the end—it's a plan that takes time and research that defines affordability and desire. Finally, the biggest purchase is a house, which will require financial assistance that has to be budgeted for depending on salary and specifically income outlays.

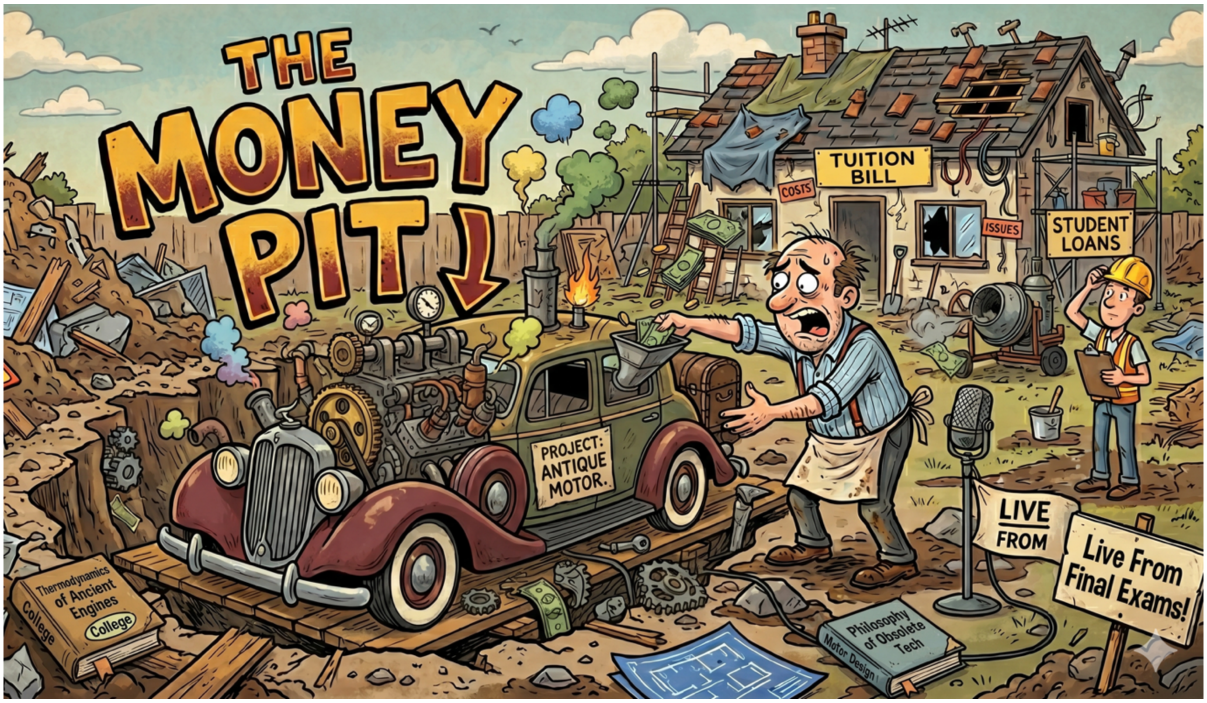

Figure 1: *Where personal funds go after leaving college, the forever debt of which motors will lose value quickly, all of which require constant attention (even colleges for retraining). AI graphic generated by Ray Ali.*

College must be paid off in several years, sometimes over 10 years; a car will likewise require a similar time period; and a house will be based on decades. For a car and house, there is constantly an upkeep in both. No one thinks twice about bringing a car into a garage every year—tires need to be replaced and brakes must be checked. Homes are the most expensive and necessary expenditure, but often the money paid for the mortgage is beyond the recommended level of 28% of gross income. In fact, "One-quarter of Americans say they have skipped meals to cover their monthly expenses, while one-third report delaying or skipping medical care." While this brings in other discussions of personal finance, the most important one is the upkeep of homes. Over time, and as long as there is no major natural catastrophe, property values keep rising, which naturally means, unlike a car, a home's value is going to keep growing [7].

No one expects to run a vehicle for free, and currently with oil prices at a premium, it's expensive to fill a car with gas. However, as much as no one wants to pay these prices, it just must be done carefully but constantly, otherwise the vehicle will simply sit on the road not moving.

The same can be said for home ownership. Constant repairs—and the biggest is the maintenance: mowing the lawn, gutters, broken fences—all come under the responsibility of a home owner. Not only do 65% of all US homeowners need to maintain their properties for their own comfort, but they also have a Home Owners Association (HOA) to answer to. The history of HOAs can be found elsewhere, but in short, they are perceived to be enforcers of the community rules, some of which can predate most property owners and follow strict rules for residents' upkeep of their own properties. However, this also means that HOAs must likewise keep commonly held community areas up to a standard in keeping with the community's foundation. A community in general has few assets that require maintenance, but they include landscaping (a running cost and not an asset), a clubhouse, brick and wood fences (fixed assets), swimming pools, playgrounds, and parks where possible (amenities). While landscaping will cost between 20–50% of the total outlay of an HOA, it is not the one that can lead to disasters. The fixed assets are a high risk and consequentially need to be examined all the time. In Houston, with the high humidity, is a prime location for damage done to these assets because of water, UV exposure, mold, mildew, termites, and bacterial erosion. Many of these issues have been dealt with (ref our papers) but do not tackle the ones at high risk [8,9].

Water Damage

Water invasion into porous construction materials (e.g., natural stones, concrete, grout, stucco, drywall, plaster, wood, wood-based composites, etc.) is the leading cause of accelerated structural degradation and ultimately premature material failure, often leading to exorbitant remediation costs. Surface treatments are regarded as a cost-effective way to combat water invasion, as most forms of degradation primarily commence at the surface prior to incursion filtrating further into the bulk of the material. Apart from the functionality of a given surface treatment, an equally important aspect in developing a robust functional coating that can withstand perennial solar and environmental detriments is the underlying composition of the coatings itself (i.e., the host matrix), enabling it to withstand perennial solar and environmental attacks.

Figure 2: *Damaged walls of different brick types that show efflorescence, mold, mildew, and water damage through delamination and loss of concrete. Photo credit S. Curran.*

The active structural components in most commercially available coatings and sealers today are primarily organic in chemical composition (i.e., carbon-based systems). Such systems typically implement various forms and/or combinations of polyester-, polyurethane-, epoxy-, latex-, or acrylic-based polymers, all of which are largely archaic in application. Irrespective of the ubiquitous designed use of carbon-based coatings, organic polymers are highly susceptible to degradation, predominantly in exterior applications, where direct exposure to sunlight, temperature fluctuations, and other weathering elements are prevalent [1]. One of the concerns in using acrylics is that they are primarily thin films, but when applied using the process of solvent wetting, they leave an undesirable film that resembles a discolored surface. Even when made of the same components, the material can pull away and leave wave formations and even pinholes, weakening the potential of having any form of waterproofing. Polyurethanes can be sprayed on but leave a foam-like finish that is susceptible to water damage and leaking, which results in the masonry below delaminating.

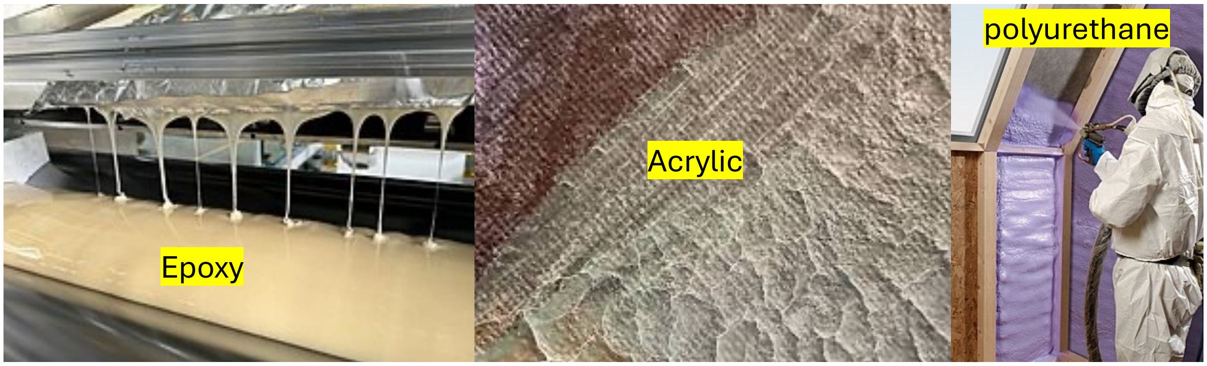

Figure 3: *This image on the left shows aerospace-grade epoxy resin used in prepreg manufacturing, acrylic finish demonstrating uneven finishes including wave like formations and on the right polyurethanes that end up in an aerated finishing,*

Specific environments must be recognized where these organics can be used, and it is imperative to strive in looking for materials for which they cannot. Most of these finishes were originally designed for indoor applications or as forms of paint thin films but have since evolved into outdoor applications as markets demand and not just driven by research. Little or no research has been focused on understanding where semi-inorganic systems based on organosilanes prevail. It is an area that has not been exploited in any significant manner, yet composites with metallic nanoparticles have already found their niche in the cosmetic industry generating over 20 billion in revenues, yet the breadth of these technologies has not even been touched on.

Figure 4: *Damaged brickwork through years of neglect (lower image) and the wall cleaned and sealed for over 5 years with no delamination (upper*

image). The location is the former Schlumberger HQ in downtown Houston off Highway 45. All buildings from 1–5 were treated with sealant to protect against environmental effects.

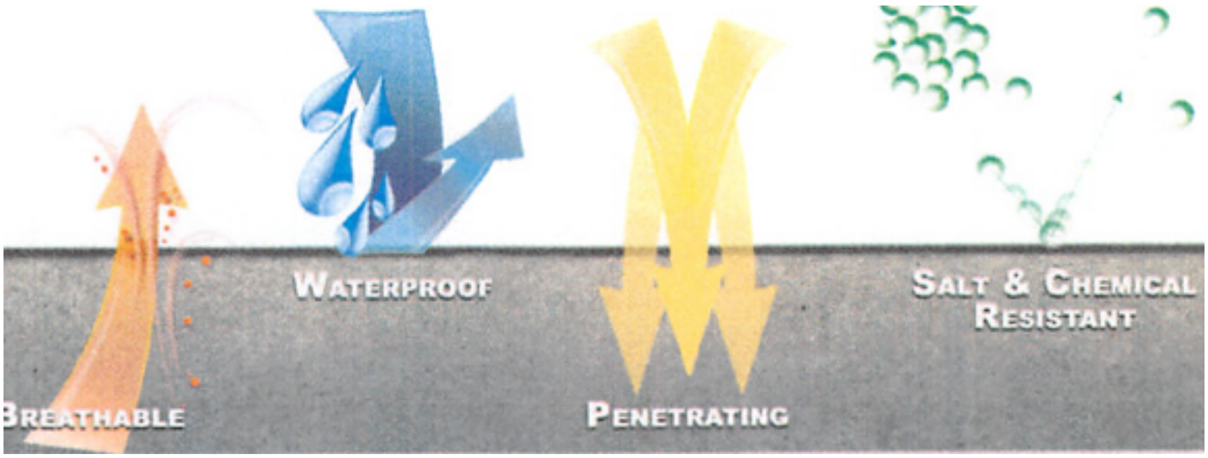

Figure 5: *Resistance to water, chemical and salts while remaining breathable as a penetrating sealer is why the use of Nano-based technologies is a vast improvement on acrylics and epoxy materials.*

Concrete and brick remain the most ubiquitous construction materials in the United States, forming the bulk of most structures in urban areas and the highways, roads, and bridges that connect them [2,3]. The weathering and subsequent degradation of 30% of all porous construction materials, including concrete, is attributed to water intrusion through biodeterioration [4,5]. Biodeterioration refers to the degradation of a material through the actions of microorganisms, including mold, mildew, algae, lichen, bacteria, and protozoa, all of which are part of the natural environment. In addition to aesthetic defacement of exposed surfaces, these microorganisms are known to degrade concrete through either the excretion of metabolic intermediates, end-products (e.g., organic acids), and/or exoenzymes [6,2]. Irrespective of the mechanisms of action, essentially all these microorganisms require water as a key nutrient for survival, rendering aquatic/marine regions or regions of high relative humidity (>70%) and moderate temperature (20–35 °C) most susceptible [reference our paper on bacteria].

Figure 6: *Degradation of walls through organic matter such as bacteria, lichen, mold, and mildew. Mold and mildew on brick walls at New Territory, Sugarland in the greater Houston area. This work will last up to 7 years before signs of growth and water damage will appear. The HOA runs the community operations that keeps the environment in such a manner that curb appeal is maintained because the whole appearance of the area is well managed.*

Figure 7: *First Colony patio area with pool where the tiles are enhanced in color, bringing out the natural look of stone after the oxidation has been removed and the penetrating sealer is used to protect the stone.*

Structural materials suffer from environmental damage caused by the actions of water, microbial organisms, fungi, and light (UV and infrared (IR)). A unique organosilane sol-gel chemistry has been developed that incorporates these molecules into the smallest of voids when carried by alcohols (solvent) into a wide variety of porous substrates. The alcohol evaporates and the sol-gel molecules then start a cross-linking process to each other and to the substrates they are protecting, creating a barrier for water incursion. This chemistry also allows us to carry in different molecules along with the sol-gel organosilanes, locking them in place through the cross-linking process. Benign antimicrobial and antifungal agents in the sol-gel create the potential to reduce or prevent damage caused by these microorganisms. The spray-on application process is a unique way of providing protection for both old and new structural materials [2].

Home Owners Associations

The history of HOAs in the US can be dated as far back as the 19th century, known as 'garden city' residential associations, a method of urban planning that first swept a lot of large-scale preplanned communities. This has a long and storied history, at one stage being used as a method of community segregation, to one that aided communities in dire need for family recreational areas. This has been done in partnership with many urban planners and developers today and accounts for >67% [9] of all new construction and community development. This means most homeowners will have to pay a management company or employ their own management team to take care of the development. These management teams can be from outside sources where property managers manage several communities (Inframark or Crest management, both all over Houston, TX and beyond) or directly employed by the community itself (First Colony or New Territory in Sugarland, TX).

Figure 8: *These monument signs were being constantly damaged by mold, mildew, water degradation, and constant pressure washing. Treatment with a penetrating cross-sealing silicon-based coating maintains the properties for up to seven years, 4 to 6 years' improvement on current offerings from old paint companies.*

HOAs routinely are involved with complaints, legal maneuvers, and lawsuits. Chief among the reasons for lawsuits (and wins) include:

Negligent Maintenance:

- HOA failure to maintain common areas leading to property damage.

- *Wrongful Liens/Foreclosure:* HOAs placing liens for disputed or invalid fines, sometimes over small amounts.
- *Unreasonable Restrictions:* Denying, then reversing approval for, improvements.
- *Discrimination/Harassment:* Violating fair housing laws or bullying residents.

The first reason is very significant, especially since residents rely on the assets when moving and need the revenue for purchasing new property. Having poorly maintained properties under direct control—and not the homes—will reduce the overall valuation. That means broken down playgrounds, playgrounds with broken masonry surfaces, wall pillars into HOA-managed areas, swimming pools falling under disrepair, HOA leisure centers and gyms, and, in particular, masonry and wood fences. If these areas are kept clean, free of mold and efflorescence staining and water damage, they can increase the value of properties by 5–6% [9].

Materials and Methods

When a polar molecule like water comes into contact with a non-polar surface, the water will bead up instead of spreading and dampening the surface. In bulk liquid water, molecules form a dynamic network of hydrogen bonds that are constantly breaking and reforming on picosecond timescales. This disordered state causes local dipole moments to largely cancel out. However, at a hydrophobic surface, water molecules cannot form favorable hydrogen bonds with the nonpolar coating. As a result, they reorganize into a more ordered, cage-like structure near the interface to maximize hydrogen bonding among themselves. This ordering restricts the rotational freedom of the water dipoles, leading to a net polarization field at the water-surface interface rather than random cancellation. The resulting polarization helps stabilize the formation of a discrete water droplet by increasing the interfacial tension and favoring water-water cohesion over water-surface adhesion.

This behavior is a direct manifestation of the hydrophobic effect. The hydrophobic effect is primarily entropic in nature: non-polar surfaces force surrounding water molecules into more ordered structures, decreasing system entropy. By beading into a near-spherical shape, the droplet minimizes contact area with the hydrophobic coating, allowing water molecules to regain disorder and restore favorable hydrogen bonding in the bulk. Macroscopically, this is described by a high contact angle (typically greater than 90°, often 110°–150° or more on well-coated surfaces) according to Young's equation that explains why water beads up on hydrophobic surfaces.

The sol–gel method allows the preparation of transparent, solid and porous inorganic matrices at low temperature, and the incorporation of organic molecules in its porosity. The method involves reactions of hydrolysis and condensation of silicon alkoxides to produce a 3-D, amorphous, porous and stable silica network. Organically modified alkoxide precursors are an excellent modifier of the structural properties of these materials' porous surface, as they allow controlling the polarity and size of the pores according to the nature and amount of the non-hydrolysable organic group used. In addition, these matrices allow the introduction of large amounts of organic molecules, especially those with large organic modifiers.

The critical role in this hydrophobic nanocoating is the behavior of cross-linking which refers to the formation of covalent bonds between polymer chains that create a three-dimensional network structure. Cross-linking helps enhance the mechanical stability, adhesion, and chemical resistance of hydrophobic coatings. In hydrophobic materials, cross-linking helps maintain surface roughness and prevents degradation, which are both essential to having high contact angles and preventing liquid absorption into porous materials such as masonry or bricks used on walls. The sol-gel process formed a crosslinked oxide network, while the additive introduced nonpolar functional groups to the surface, reducing the surface energy. Combined with nanoscale roughness inherent to sol-gel films, this resulted in a hydrophobic coating characterized by water repellency.

SCHN 158 was tested for denaturation at temperatures as high as 350℃, proving to remain stable and fully functional. Its high melting point is likely due to strong covalent bonds with high bond energies that can withstand the kinetics of its environment [5].

Results and Discussion

Using unusual nanomaterials, a series of nano-coating technologies based on organosilane sol-gel chemistry has been designed to impart water-/weather-proofing properties to a wide range of porous and non-porous materials including glass, aluminum, fabrics, wood, and masonry [2–6]. For porous materials, the underlying technology is rooted in a sophisticated bottom-up molecular system that, in effect, forms a tailorable protective interpenetrating inorganic network that seeps into a material to form a nano-/micro-structured barrier from the inside out. This hydrophobic barrier was originally designed to lock desired functionalities/properties in while concomitantly reducing the effects of environmental elements detrimental to the integrity of otherwise untreated host materials. In doing so, this technology also accommodates the option of imparting a variety of selective functionalities to the bulk and surfaces of certain substrates that such materials fail to ordinarily or intrinsically exhibit, including mold/mildew resistance and solar/heat management. This is accomplished by both chemically and physically immobilizing functional additives into/onto the host material in a proprietary manner.

Two fundamental facets comprise the cornerstone of this technology, which holistically differentiates it from other existing technologies:

1.) The mechanism by which the technology protects a given host material

2.) The ability of the technology to function as a penetrating delivery system for an assortment of additional functional additives (e.g., IR-reflectants, biocides, flame-retardants, UV stabilizers, etc.)

In contrast to most polymeric coatings, our molecular system percolates through porous materials while intimately interacting with the molecular structure of a suitable host/substrate material to form a three-dimensional protective barricade against the elements. This is functionally different from conventional sealers, lacquers, varnishes, enamels, or glosses that merely form an easily erodible surface coating. As a result of the robust encapsulation mechanism, the core platform technology is also proficient at extending the useful life of construction/building materials while concurrently reducing the frequency of coating reapplication, mitigating the costly tax-dollar and time-consequence repercussions typically associated with conventional alternatives [5,2].

Masonry (Structural)

A hydrophobically-modifying functional coating system has been developed for porous materials that directly addresses this issue by penetrating porous materials like concrete, effectively encapsulating the granular structure and sealing off voids that facilitate the retention of water. We now wish to combine this material with the ability of our coating system to deliver an assortment of environmentally preferred biocides to target more resilient microbial organisms, which will significantly reduce the degree of biodeterioration in porous construction materials like concrete and explore how long this treatment will extend the useful service life and resilience of the concrete-based materials. Critically, performance in real-world conditions is considered through thorough field-testing in Houston, which is notoriously hot and humid, and thus an ideal breeding ground for fungal and microbial organisms.

Objective I – Water Repellency and Weather Resistance

In response to increasing demand for more effective coatings that resist water/weather damage, CNRG has developed a series of formulations based on the aforementioned platform technology specifically designed for porous construction materials (e.g., natural stones, concrete, grout, stucco, drywall, plaster, etc.) commonly implemented in the external and insulating layers of enclosed urban structures. These coatings provide excellent protection from water invasion. As shown in Table 1, ASTM standard tests carried out in our laboratory show great water repellency efficiency (WRE) in standard concrete, stucco, and grout samples [10,11].

The testing criteria include:

- Penetrating and non-film forming (no acrylic or urethane resins)
- Ability to re-coat without removing or stripping previous application
- Must not contain any polyaromatic hydrocarbons/creosote, oils, waxes, or fluorocarbons, or formaldehyde
- No change in the appearance of the brick being sealed
- No whitening or yellowing of surface due to sunlight
- No glossy finish or always-wet appearance after sealer cures
- Non-carcinogenic per the sealer material Safety Data Sheet (SDS)
- SDS of sealer material must be supplied and be accurate and up to date
- SDS must be in the updated format in accordance with UN Globally Harmonized System of Classification and Labeling of Chemicals (GHS) [i.e., have all 16 sections]
- Acid resistant
- Must contain EPA-approved fungicide and mildewcide additives to protect the sealer finish

- Must maintain a water repellency efficiency following test methods for cementitious materials as a standard:
    - ASTM C1585 >90% (20 days)
    - ASTM C642 >95% (30 minutes)
    - ASTM 1757 >85% (48 hr.)
- ISO 1523
- ASTM D3828
- ASTM D4060 inc.
- ASTM D823 – Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels
- ASTM D968 – Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
- ASTM D1005 – Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
- ASTM D2240 – Test Method for Rubber Property—Durometer Hardness
- ASTM D3924 – Specification for Environment for Conditioning and Testing Paint, Varnish, Lacquer, and Related Materials
- ASTM D7091 – Practice for Nondestructive Measurement of Dry Film Thickness

Poor Property Management/Maintenance

Neglected common areas and perimeter walls, including deferred landscaping, poor building exteriors, or broken amenities, signal mismanagement. This often causes lower appraisal ratings, fewer potential buyers, and reduced marketability for homes, even in desirable locations.

> **Declining Aesthetics:** Unkempt landscaping, peeling paint, and neglected common areas immediately reduce curb appeal.

Deferred Maintenance: Procrastinating on repairs leads to safety risks and higher long-term costs, often necessitating large special assessments that deter buyers.

Reduced Buyer Pool: Buyers and lenders often shy away from communities with high delinquency rates and poorly maintained exteriors, particularly with townhomes or condos.

Lower Appraisals: Appraisers look beyond the interior, considering the overall health of the association and the quality of common maintenance.

Legal and Financial Consequences

Lawsuits: Homeowners may have grounds to sue an HOA if a failure to maintain common areas leads to property damage or personal injury.

Mortgage Difficulty: High fees or major special assessments can impact a buyer's debt-to-income ratio, making it harder for them to secure a mortgage.

Beware residents: If an HOA recognizes that they have a fence wall that requires treatment, they may clean one side and ignore the other, only warning residents that they also need to maintain the fence from their side as well. There are cases where a whole series of obligations are listed out alongside the perimeter fence, such as telling residents that it is their responsibility to keep the inside of a wall from plants and growths. When the wall subsequently delaminates, residents are blamed and HOA management stays within a limited budget. This can delay the sale of a property, a remortgage, and/or a refinance, so residents end up—right or wrong—paying up. This is more the practice for large-scale operational HOA companies, of which 65% of all current US residents are governed by. Municipal Utility Districts (MUDs) in Texas are beginning to restructure in a similar manner, making this an area of contention while maintenance is ignored and can be done in an inexpensive manner [9].

These conditions significantly reduce property valuations by decreasing curb appeal, signaling financial instability, and limiting the pool of potential buyers. While a well-managed HOA can increase a home's value by 5–6% compared to non-HOA properties, neglect and mismanagement can have the opposite [12,13] effect.

Power Washing and Cleaning

In addition to imparting enduring protection against the damaging effects of water invasion, which result in costly remediation, our coatings also aesthetically enhance natural stones by accentuating grain structures that are normally obscured. With practical applications in mind, our coatings for porous construction materials exhibit fast-drying technology that expedites the application process for professional contractors with a single-coat spray/roll application with coverage equal to or greater than comparable commercially available coatings. Typical dry times are between 10–15 minutes with a full cure obtained within 24 hours with no laps, runs, or streaks, significantly reducing the amount of time required to complete new or retrofitting coating projects.

Figure 9: *To clean red brick safely, use 500 to 1,500 PSI (pounds per square inch) with a wide-angle nozzle (25°–40°), ensuring the tip stays at least 12 inches from the surface to avoid damaging the mortar. For older or delicate brick, use even lower pressure or a soft-wash method. A pressure washer nozzle is designed to send powerful jets of water to clean surfaces, sometimes with the unintended consequence of damaging inside concrete or brickwork. This uses a nozzle creating cone-shaped sprays for highly directed water into specific areas. The nozzle type can be from almost 0° to as much as 40°, and this will allow different pressure levels striking a surface.*

Gaining an Insight into Cleaning: Pressure Washing

The nozzle of all pressure washers is interchangeable. This means the control of water with a suitable pressure-driven system can be used to clean walls or induce cracking. The plume of the washer can be seen as a cone that uses internal geometry to deflect the high-pressure stream into a fan or circular cone shape. As the water spreads, the impact pressure decreases, but the coverage area increases.

Figure 10: *The damage that can be caused by poorly skilled pressure washer technicians.*

Replacing a brick fence generally costs between \$50 and \$100+ per linear foot or \$25 per square foot on average, with total projects often ranging from \$2,400 to \$9,000+ depending on height and length. Costs include materials (\$10–\$45/sq ft) and labor. Large projects for 2–3 miles: building one mile (5,280 linear feet) of brick fence is a major construction project that can cost as little as \$350,000 for wall fences with a simple design. Using nanotechnology on the same walls means no disruption in the scale of the community and no unwanted repairs, but at a cost that provides longevity of these assets and a very visible, clean, fresh look. This treatment process can last many decades and provide preventive methods for water damage.

Typically, there are many companies that offer pressure washing services with a simple logic: blast the surface of masonry to clean off the surface, but this causes so many fractures in the masonry that it leads to damaged surfaces. Pressure washing a fence typically costs between \$110 and \$300, with an average national price of roughly \$200–\$225 for a standard 500-square-foot (approx. 80–100 linear feet) wooden fence. Prices usually range from \$0.25 to \$0.90 per square foot or $1 to $3 per linear foot depending on fence material, height, and grime buildup. Coating the same areas with the nanotech sol-gel can come in at a premium yet provide protection and curb appeal for up to 7 years on the outside. The bigger benefit of doing such a treatment is that the masonry does not degrade and so the assets remain looking good, curb appeal is saved, and lower premiums are paid by residents [14,9].

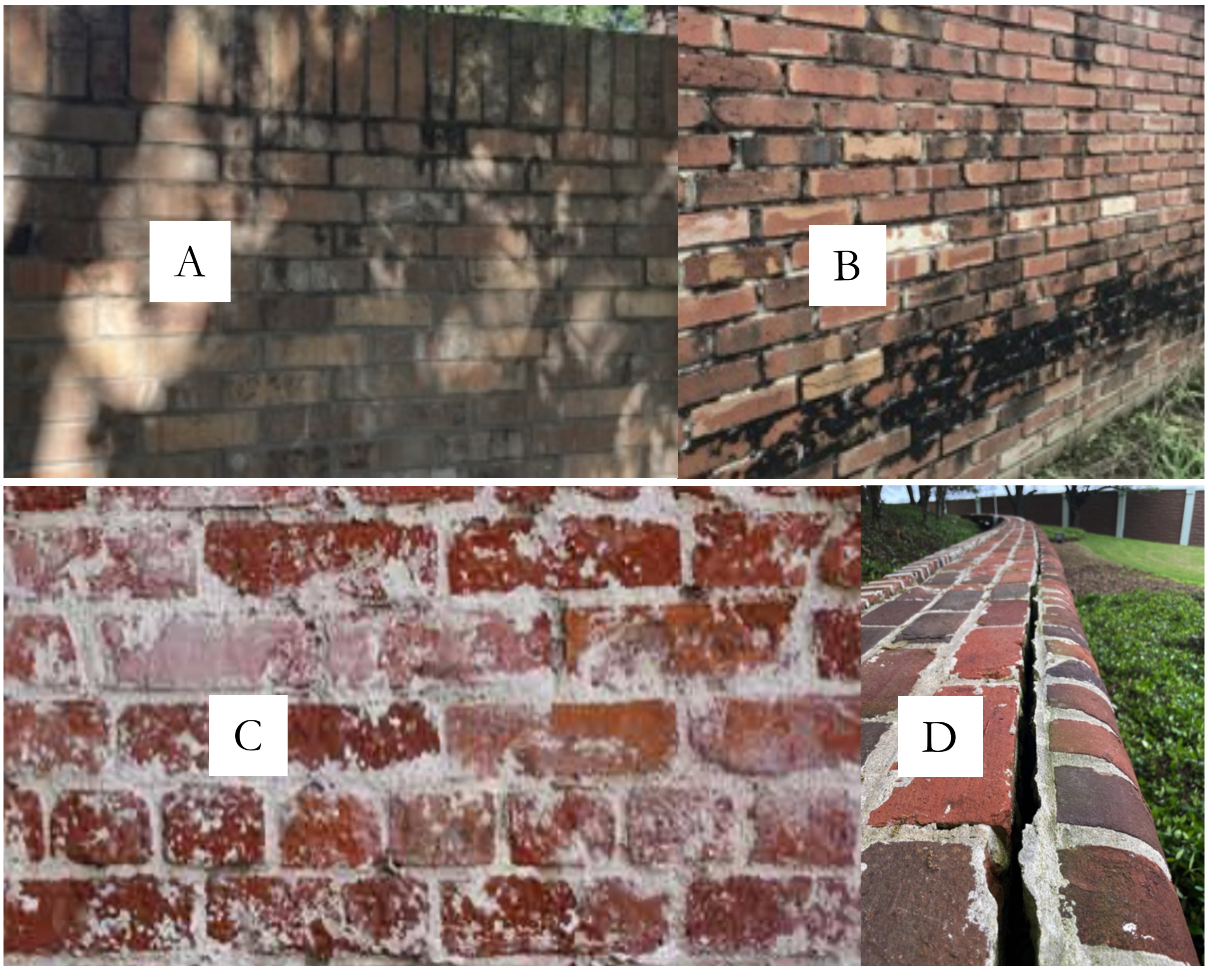

Figure 11: *a) Brick wall suffering water damage (park in Sugarland) and b) mold growth (Greatwood, Sugarland) in areas that are untreated and will cost the residents huge costs when the walls collapse. Neither of these areas have been treated but residents will find out the costs in the near term from delamination.*

Walls that were being damaged in 2017 and 2018 were all treated by First Colony in Sugarland, TX and are now well maintained, showing a fresh finish giving the area an appeal for sellers of the properties. These are due for renewal so that repair costs remain low and the walls look fresh, maintaining curb appeal. Without this treatment, the result will be water damage, constant yearly maintenance costs, eventual replacement cost, and the potential for losses in property valuations that could end up in lawsuits as has been the case recently elsewhere [12].

Large Property Buildings

Water Damage in Buildings: A Comprehensive Guide

Water damage is one of the most common and potentially destructive problems a building can face. Whether it stems from a slow, hidden leak or a sudden, catastrophic flood, water can compromise structural integrity, destroy property, and create severe health hazards. Early detection is critical to minimizing repair costs. While a flooded basement is obvious, many forms of water damage are insidious and hidden [15,12,9].

Visual Indicators

- Water stains or discoloration on ceilings, walls, or floors.
- Bubbling, peeling, or flaking paint and wallpaper.
- Warping, buckling, or cupping of wood floors.
- Sagging drywall or ceilings.
- Unexplained rust on metal fixtures or exposed pipes.

Olfactory Indicators: A persistent musty, damp, or earthy odor is often the first sign of hidden moisture and mold growth.

The restoration industry (IICRC standards) classifies water damage into three categories based on the level of contamination and the threat it poses to human health.

- *Category 1 (Clean Water):* Originates from a sanitary source. Examples include broken water supply lines, tub or sink overflows (with no contaminants), or falling rainwater. If left untreated, Category 1 water can quickly degrade into Category 2 or 3.
- *Category 2 (Gray Water):* Contains significant contamination and has the potential to cause discomfort or sickness if consumed or exposed to humans. Examples include discharge from dishwashers or washing machines, overflows from toilet bowls (containing urine but no feces), or sump pump failures.
- *Category 3 (Black Water):* Grossly contaminated and contains pathogenic, toxigenic, or other harmful agents. Examples include sewage backups, rising floodwaters from rivers or streams, and standing water that has begun to support microbial growth. This requires highly specialized handling and extensive protective gear.

The consequences aside from structural delamination include:

- *Mold and Mildew:* Mold spores can begin growing within 24 to 48 hours in damp conditions, leading to severe indoor air quality issues and allergic or respiratory reactions in occupants.
- *Electrical Hazards:* Water interacting with electrical systems poses severe fire and electrocution risks.

Figure 12: *This is what will happen both on the interior and exterior of buildings simply caused by water damage, leading to mold and mildew, as well as efflorescence (white color) and physical delamination of the walls.*

Figure 13: *Building 2 at the Technology Bridge at the University of Houston after 7 years of exposure to freeze (20°F) to heat (105°F) with humidity levels of >95%, surviving 2 hurricanes.*

These buildings are part of the University of Houston, where it has been found that protection has been provided for 7 years. These walls were built in the 1970s and 1980s where waterproof coursing was not part of the construction. The consequence was that over time water wept from the outside into the building, damaging computers and paper files while causing a rising risk of mold and mildew sickness simply from staying within an interior space. These buildings are not designed for architectural beauty but for functionality; however, going to a clean and fresh space makes a work environment far better for employees while also reducing the risk of delamination. This also occurred on main campus at the University of Houston, where water kept seeping into the inside of the building space and resulted in a multi-million dollar facelift to reduce the risk of water damage.

Economic Analysis—what it costs homeowners (YOU)

Poorly maintained areas will reduce value by 12% through deferred maintenance [14,12], which is why a well-thought-out strategy for aging infrastructure is needed. What does this mean in the real world? If a property is equal to $300,000 in the Houston area, then poorly maintained HOA-managed areas represent a loss of $24,000, and with a loss of $12,000 from the potential value of a property, that's a total loss of $36,000 to the homeowner. With seller's fees at 6%, that accounts for $18,000 [8].

Poor HOA Maintenance

2 Story House	**$300,000.00**	**% change**			
Listed Price	$300,000.00	0%			
Valuation (potential) Increase	$18,000.00	6%	HOA Fees/Resale	$500.00	1.8%
HOA Maintenance Loss	$36,000.00	12%	Local Property Tax	$3,960	1.5%
Sellers Fees	$18,000.00	6%	Escrow and Settlement	$2,640	1%
Title Insurance	$2,640.00	1%	Attorney Fees	$115	<0.1%
Repairs and Staging	$3,000.00	1%	Recording Fees	$35	<0.1%
Base Selling Price	$264,000.00	12%	Seller Concessions	$7,920	3%

Before mortgage/loan costs are considered, a house sold for $264,000 will have roughly $92,810 in costs, and the HOA losses through poor maintenance will be $54,000. If a homeowner has also spent $500 per month over 10 years, that's a further loss of $5,000. This is the true cost of HOAs and the difference between poor maintenance and areas that are desirable for new property owners.

Conclusion

Through hard work and ingenuity, this technology has developed beyond initial expectations. Using unique platform technologies (like a 'sol-gel'), a series of formulations have filled in spaces within many types of construction materials used in building, generally known as concrete. The materials, self-cleaning hydrophobic nanocoatings or SCHN, will cross-link with each other to form a web/network that prevent anchor sites for organic matter build-up and acts as a superhydrophobic coating. While not explored in this article, these coatings also prevent erosion caused by changing pH values, so coated materials can withstand all forms of acid attack. Beyond these properties, composite formation which is mixing of two bodies that are different and possess their own unique properties can also be incorporated. This means the SCHN coatings can have a colored aspect, be designed to be 100% termite resistant and even be used as a thermal energy generator. A consequence of this chemistry is that designing solgels in general can be the next avenue of interest for researchers in composite formation, an area that is ill served so far in research. The current formulations from CNRG demonstrate real world benefits and have been tested successfully all over Houston as a starting point, which is shown in Figure 14.

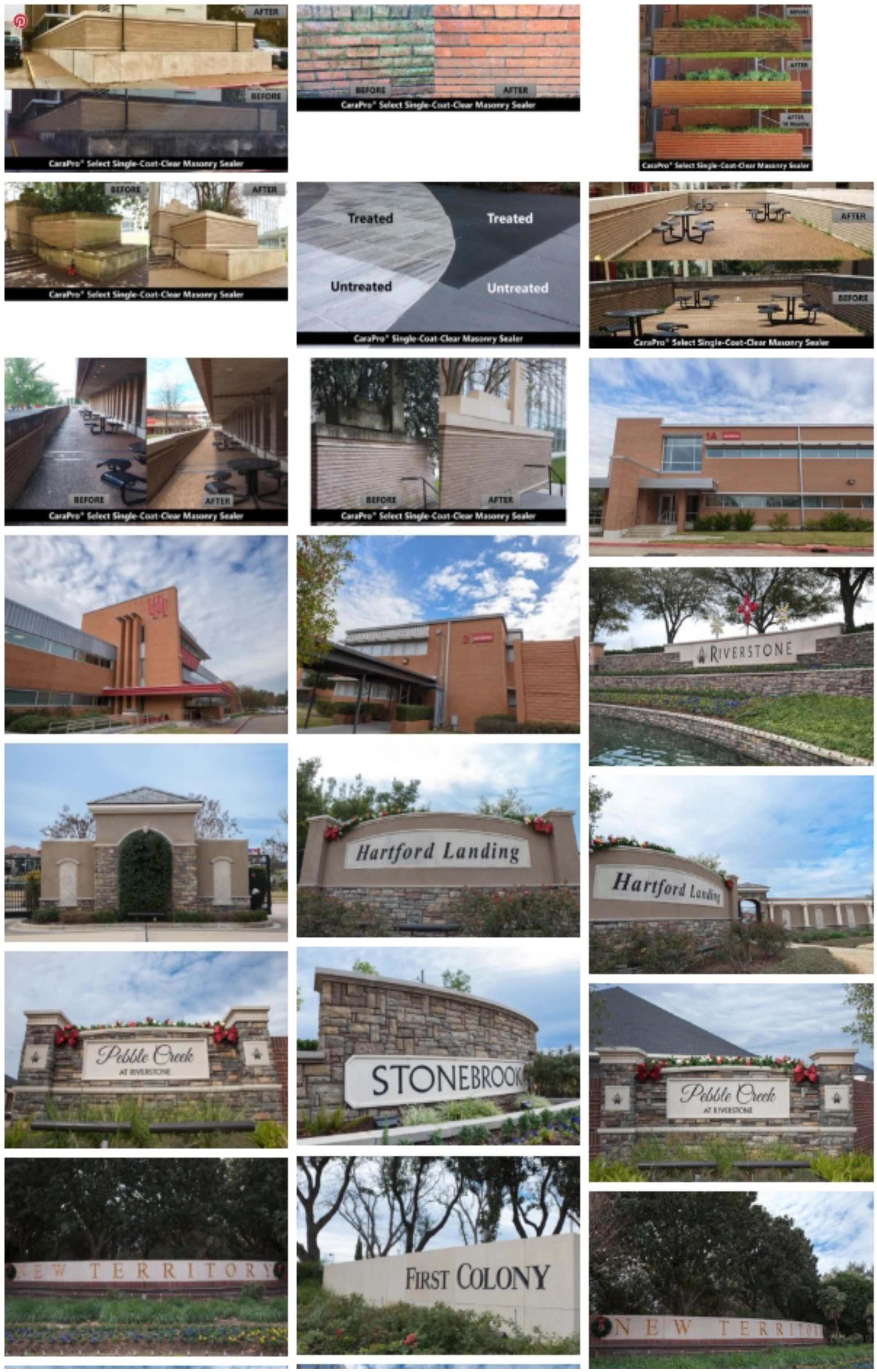

Figure 14: *locations of some of the areas that have been treated.*

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