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BUILDING FOR THE FUTURE: SEEING BUILDING MATERIALS IN TERMS OF WEATHERING AND LONGEVITY

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Abstract. Classic designs have the charm of a good pair of brogues. They last for years and the older they are the better they fit. As in shoemaking, engineers and scientists have since the 18th century developed lighter and more flexible construction materials in the name of "progress" and "efficiency." Indeed, although the variety of traditional building materials is great, its range is limited to thatch, wood, clay, lime, stone, metals, and glass—and Roman cement, pozzolana. And there are reasons for that. Today, Despite the high energy and environmental costs of their production—and the extraordinary long tail of pollution that most plastics inhere, plastics and plastics derivatives are being intensively promoted for their apparent flexibility, durability, lower costs, and energy and weathering efficiency in construction. Indeed, this field is the world's largest consumer of plastics after packaging. But the question remains whether plastics are viable in construction. The short life of the products, combined with our inability to recycle or degrade them, makes them long-term costly, if not dangerous, environmentally.

Keywords: *classic design, building materials, weathering, plastics, embedded energy, environmental costs, long tail of pollution, recycling.*

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1. Introduction

It is easy to write off structurally "old" as "inferior," but it is simply not necessarily true. Traditional structures do not have much lateral strength, but their flexible construction lacks the stiff elements which attract the full force of destruction. Although their masonry and mortar are brittle, these structures system behave as if they were ''ductile.'' Compared to modern designs, non-engineered, vernacular construction with comparatively weak materials have in many cases proven more robust than expected (Langenbach, 2013, 2016).

Although the variety of traditional building materials is great, its range is limited to thatch, wood, clay, lime, stone, metals, and glass—and Roman cement, pozzolana. And there are reasons for that.

Traditional building materials have been selected and developed over thousands of years to not only deliver structural strength, but to also withstand weathering. Stone, brick or concrete buildings as well as statues, monuments and ornamental stonework can be badly damaged by natural weathering processes. Weathering is the breaking down of materials through in situ contact with the Earth's atmosphere, water, and biological organisms. It occurs with little or no movement, and can involve agents such as rain, water, ice, snow, wind, waves, and gravity, as well as dust, sand and other particles transported in the environment. This is accelerated in areas severely affected by acid rain.

Mechanical or physical weathering involves the breakdown of materials through direct contact with heat, water, ice and particle abrasion. It is accentuated in very cold or very dry environments. Chemical weathering involves the direct effect of atmospheric chemicals, and is most intense in wet and hot climates. Biological action involves both the direct physical action of organisms on a material, such as eating it or burrowing in it, and that of chemicals produced biologically resulting in the breakdown of materials.

When the types of weathering occur in combination, each tends to accelerate the other. For example, the rate of disintegration in cracks created by physical weathering will be amplified by exposure to chemical action. Water, ice, and wind processes loaded with particles, can have tremendous abrasive power. Disintegration caused by plant roots entering cracks and prying them apart, may be augmented by the burrowing of animals and ultimately result in structure collapse.

Thermal stress weathering results from repeated expansion and contraction of materials caused by temperature changes. Heating stone and brick by sunlight or fires can cause expansion and as some minerals expand more than others, temperature changes set up differential stresses that eventually cause the material to crack apart. Since the outer material surfaces are often warmer or colder than the more protected inner portions, some rocks may exfoliate, the outer layers peeling away. Such a process may sharply accelerate if ice forms in the surface cracks, expanding with an enormous force and disintegrating large blocks of material. The approximately 10% (9.87) expansion caused by water freezing into ice can place considerable stress on anything containing the water as it freezes. Moisture as well can enhance thermal expansion. At some point the stress can exceed the strength of the material, causing a crack to form, and if nothing stops it from propagating, the material is likely to fail.

Chemical weathering such as haloclasty is a type of physical weathering caused by the growth of salt crystals as a result of salt water seeping into cracks and evaporating to deposit salt crystals. When the rocks are heated, the crystals expand putting pressure on the surrounding stone which over time fragments it. Salt crystallization also takes place when solutions decompose marble and limestone to form sodium sulfate or sodium carbonate solutions, from which water evaporates to form their respective crystals, which can expand up to three times or more in volume. This is normally associated with arid climates where strong heating causes strong evaporation and is also common along coasts as exemplified by the salt weathering and honeycombing observed in sea walls. Chemical weathering is enhanced by such geological agents as the presence of water and oxygen, as well as by such biological agents as the acids produced by microbial and plant-root metabolism.

Rainfall is acidic because atmospheric carbon dioxide dissolves in the rainwater producing weak carbonic acid. In unpolluted environments, the rainfall pH is around 5.6, but acid rain occurs when gases such as sulfur dioxide and nitrogen oxides are present. These react in the rain water to produce stronger acids and can lower the pH to 4.5 or even 3.0. Sulfur dioxide, SO_2, which comes from volcanic eruptions or fossil fuels, can become sulfuric acid within rainwater, causing solution weathering to the stone and metals on which it falls.

Figure 1. Salt weathering of building stone on the island of Gozo, Malta
https://commons.wikimedia.org/wiki/File:Salt_weathering_in_gozo.jpg

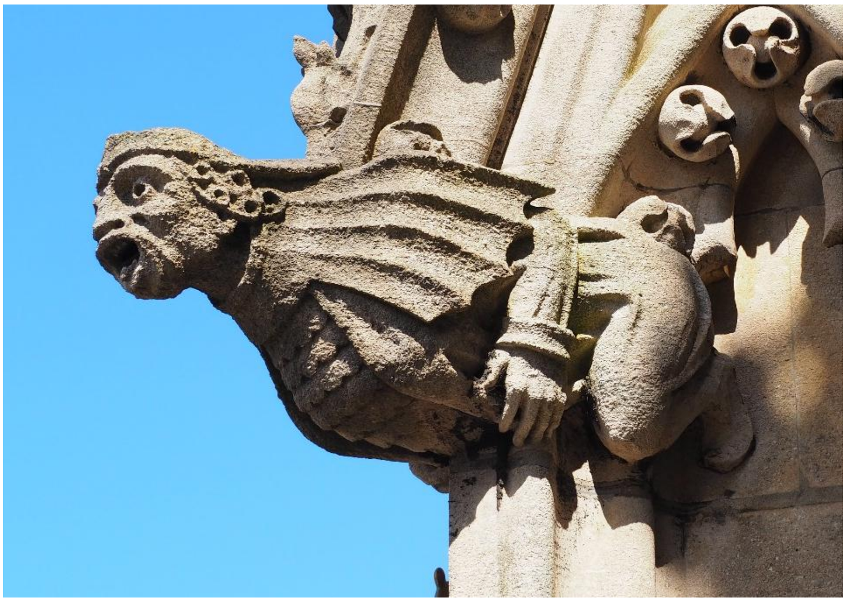

Figure 2. A tree invades a temple, Angkor Wat
Figure 3. Lichens and mosses, Angkor Wat
Figure 4. Atmospheric weathering, Oxford, UK. Images courtesy Nir Buras

Carbonation also occurs on marble, limestone and chalk, stones which contain calcium carbonate, when rain combines with carbon dioxide or an organic acid to form a weak carbonic acid which reacts with the stone and forms calcium bicarbonate. Since colder water holds more dissolved carbon dioxide, this process is sped up at lower temperatures.

Obviously, the chemical oxidation of metals causes corrosion, most commonly observed in the oxidation of iron, rust, but also in the patina and ultimate failure of aluminum, copper, and bronze.

Some plants and animals may cause chemical weathering through release of acidic compounds, i.e. the effect of moss growing on roofs, or horse and cow urine on stone roads and floors; mineral weathering can also be initiated or accelerated by soil microorganisms. Lichens on rocks are thought to increase chemical weathering rates three to four times compared to exposed bare stone surfaces. (Zambell *et al*., 2012).

The most common forms of biological weathering are the release of organic acids and acidifying molecules by plants which break down the aluminum- and iron-containing compounds in the stone. The symbiotic fungi associated with tree root systems which can release inorganic nutrients from minerals and transfer these nutrients to trees, does so at the expense of the integrity of the stone it inhabits.This is abetted by a large range of bacterial strains from diverse genera and communities that colonize mineral surfaces, some in symbiosis with fungi and plants. (Uroz *et al*., 2009)

In the holistic classical system, the selection and development of materials is part and parcel of the traditional design and construction of all cultures. Vitruvius, Alberti, Palladio wrote extensively about materials and their selection.The Laws of the Indies included numerous clauses that impacted material sourcing and choice. The classical Orders in fact provide the most protective method of shaping a building when it comes to protecting its joints and openings.

A traditional wall has been for thousands of years composed of three wythes of brick, plastered on the inside – and that's it. Windows—technically holes in the walls—had shutters and curtains, and were sometimes doubled by having both internal and external single glazed windows. Water generally did not penetrate all the way to the interior—the bricks simply dried out. Today's "single-component" double-glazed windows are no match for the former "four-component" window assemblies. To match the traditional wall's performance, a modern wall may have ten to fifteen layers of materials, many of them plastic.

Figure 5. Window cleaners working on a glass high-rise building
https://www.istockphoto.com/video/skyscraper-cleaning-gm472794299-15167907

From a formerly rich landscape of both built fabric and ruins, much of which can be—and has been—recycled, we are today creating toxic environments of degrading plastics the full dangers of which are not yet clear.

The growth of highrise concrete and steel frames has driven structural engineering, and modern aesthetics have driven the view of traditional masonry as old fashioned and primitive (Dixit, 2017; Aktas, 2017). Viewing pre-modern structural systems merely as antiquated may be costing the world hundreds of thousands of lives, if not millions, in seismic collapses; and untold harm in exposure to plastics. Not to mention, the wasteful regular washing that extensive glass facades require to look new, and environmentally degrading detergents that cause pressing environmental concerns now and for future generations.

As can be seen from the tilting Millennium Tower in San Francisco, losing touch with practice and common sense blurs the fine line between engineering and wishful thinking. But being oblivious to plastics in construction may be an even more fatal error.

2. Modern and classical compared

Contrary to the classical method which applies successful precedents, inventively modifying them to new circumstances, the contemporary culture frequently seeks to applyinnovative materials.

Synthetic fabrics, as used in sports clothing, seem to be the 'go-to' fabrics for many nowadays, while natural materials, like cotton, wool, tweed and corduroy, seem to be less used. Trainers, sneakers, and gym shoes,which represent “function” and “progress,”do not have thesame qualities as a good pair of brogues, and no amount of polishing will improve the situation. But as in shoemaking, engineers and scientists have since the 18th century developed lighter and more flexible construction materials in the name of progress and efficiency.Such advanced engineering can come at a great cost.

Figure 6. An old pair of trainers
https://y98.radio.com/blogs/tim-convy/look-beat-new-shoes - Look: Beat-Up New Shoes: Would you pay over $500 for beat-up sneakers with DUCT TAPE??!! SEPTEMBER 21, 2018. TIM CONVY

Indeed, many modern buildings are exactly like sneakers. They look great the first day they are used, and then progressively worse, as the concrete cracks to reveal rusting reinforcing bars and as the plastic seals fail. Many modern buildings rely on a pristine white rendered facade which requires endless painting and repair just to look reasonable. This can be seen on these images of the Villa Savoye taken before its restoration. It is interesting to note that the most iconic of all of Le Corbusier's Villas, depends on constant restoration for its aesthetic appeal. The goal is a "machine-made" look.

Figure 7. Villa Savoye prior to restoration
https://mag.lesgrandsducs.com/2014/11/villa-savoye/

To attain the Modernist goals of constructing innovative structures, many skilled construction crafts are being replaced by unskilled assembly line labor as the world works towards universal robotization. Just about any construction or job site around the world taking shape today is overrun by plastics and plastics derivatives (Barron, 2016).

But despite hindered amine light stabilizers (HALS), UV-absorbers, and antioxidants, polymer cracking, chemical disintegration, and biodegradation are typical of plastics. The degradation of the strength, color, shape, etc. of polymer-based products under the influence of heat, light, chemicals, and salts continues to challenge.

Most "commodity polymers" which make up the overwhelming majority of polymers and plastics in daily use, [1] are degraded by visible light, some are sensitive to oxidation and UV radiation, some are sensitive to hydrolysis and attack by acids, while others depolymerize rapidly when exposed to some alkalis. Although the problem of ozone cracking can be prevented by adding anti-ozonants, cracks can be formed in many elastomers by ozone coming from tiny traces of the gas in the atmposhphere. Some polymers are susceptible to attack by atmospheric oxygen, and some literally unzip or depolymerize to become the constituent monomers. PVC discolors and becomes brittle due to loss of the hydrogen chloride gas in its makeup.

The highly reactive gas chlorine will attack susceptible polymers, even in trace amounts as found in chlorinated water. Biodegradable plastics can be biologically degraded by microorganisms, in which case they need to be composted rather than dumped in a landfill where lack of oxygen and moisture inhibits microbial activity.

Unless standard corrosion protection procedures are applied in carbon fiber reinforced polymers (CFRPs), polymer degradation occurs through galvanic action similar to that of metals. When put into contact with a more active metal such as aluminum, the carbon fibers act as a noble metal similar to gold or platinum, causing the aluminum to corrode.

In whatever form or shape, the weather testing of polymers provides for far shorter timeframes for durability than the geological and archeological time that we have from observing traditional material weathering. In the rush to put materials on the

[1] Polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate [PET, PETE], polystyrene, polycarbonate, and polymethyl methacrylate [Plexiglas].

market, so-called “accelerated natural weathering” is used. The method applies mirrors to amplify available UV radiation in arrangements that in a single year can deliver doses of UV exposure commensurate with decades of its natural radiation exposure; to which water and saline solution may be added to simulate more humid climate or corrosive (coastal) ones. Artificial weathering chambers can accelerate the testing time but the tests are even less representative of real-world conditions. The Plastics Industry Trade Association itself reports that, after packaging, building and construction are the world’s largest consumer of plastics. Despite the high energy and environmental costs of their production—and the extraordinary long tail of pollution that most plastics inhere, plastics and plastics derivatives are being intensively promoted for their apparent flexibility, durability, lower costs, and energy and weathering efficiency. Plastics are being heavily pushed for residential and commercial roofing, structure wraps, insulation, windows, piping, composite “lumber” flooring and planks, moldings, and wall and floor coverings (SPI, 2016).

Figure 8. Due to their longevity, are plastics acceptable in traditional architecture?

Granted, for some pipes, valves, and fittings, plastics offer advantageous corrosion and chemical resistance. But the sulfur-bearing compounds, salt water, crude oil, laboratory waste, and other substances plastics are resistant to should never be found in standard commercial or residential supply or waste. The use of plastics in them is simply not necessary.

The growing role plastics play in ‘Smart’ designs worldwide indicates not their appropriateness, but the lack of consciousness of some designers. Though most plastics are hopefully benign in their intended use, in their manufacture and in their degradation as waste products plastics are among the worst toxic pollutants of our time.

Indeed, the plastics industry would have us ignore the consequences of long-term plastics use, the huge, increasingly recognized environmental challenges they pose in their production and fabrication, and the deleterious long term health implications for people and severe consequences identified for them with animals and the biosphere. Despite statements to the contrary, for every “solution” proposed by its leaders, the plastics industry sees, severe new problems emerge.

Figure 9. Partially demolished Children's Hospital Pittsburgh PA and its variety of modern construction materials
https://rutheh.com/2010/10/22/childrens-hospital-old-and-new/

China, India, Japan, and the US—the countries which lead the global construction sector—will suffer the greatest long-term environmental consequences of plastics production, use, contamination, and pollution by plastics waste that they produce after their useful lifetime (Barron, 2016).

3. Dangers of plastics

Perhaps the greatest failure in the world today is the introduction of plastics in construction. The short life of the products, combined with our inability to recycle or degrade them, makes them long-term costly, if not dangerous, environmentally. The rise in use of plastics in building and construction is linked to plastics' perceived utility, cost, ease of installation, and longevity. Plastics are strong but lightweight, resistant when degraded by chemicals, sunlight, and bacteria, and are thermally and electrically insulating. Plastics have become a critical material in the modern economy; the annual volume of plastics produced exceeds that volume of steel (Tammemagi, 2000). However, the idea that plastic products supersede those made of traditional building materials is true only when ignoring their long tail of environmental degradation and pollution.

Nonbiodegradable plastics cause air pollution and they pollute the soil and groundwater. They mix into the food chain effecting humans and animals. There is no safe way to dispose of plastic waste and toxic chemicals release during their manufacturing also have huge negative environmental impact. The host of carcinogenic, neurotoxic, and hormone-disruptive chemicals that are the standard ingredients and waste products of plastic production, inevitably find their way into us via air, water, and land pollution. Many of these are persistent organic pollutants and, owing to a combination of their persistence and high levels of toxicity, among the most damaging toxins on the planet (Koushal, 2014).

Occupational exposure during installation, such as inhalation of dust while cutting plastic pipe or off-gassing vapors of curing products, is a great concern for human health and the environment. The disposal of plastics is among the least recognized and most highly problematic areas of their ecological impact. Natural organisms have a difficult time breaking down plastics, and less than 10% of total plastic production is effectively recycled. The remaining plastic is sent to landfills, where it can remain entombed for hundreds of thousands of years; or to incinerators, where its toxic compounds are spewed into the atmosphere to be accumulated by life forms in the surrounding ecosystems. Whole areas of ocean, called gyres, contain millions of square miles of plastic refuse appearing in a range of sizes from molecular to confetti-like to identifiable objects, 80% originally sourced from land, including construction waste (Koushal, 2014).

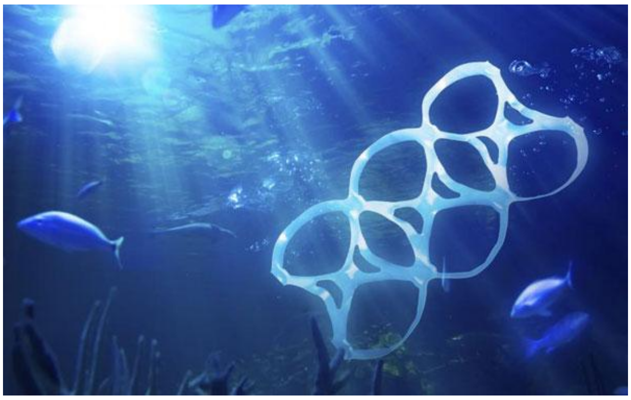

Figure 10. Caption and source by FT Plastic waste in the sea ISTOCKPHOTO/FERGREGORY - https://www.sierraclub.org/sierra/2016-3-may-june/green-life/5-innovative-ways-companies-are-using-ocean-plastic

The accelerating harmful effects of plastic on aquatic life are devastating. Ingestion of plastic waste has been documented in sea birds, fish, turtles, mussels, and mammals which mistake plastic waste for prey. Fish confuse plastic pellets for plankton, birds mistake pieces of plastic for cuttlefish, etc. Chemicals components of or additives to plastic have known negative effects on human and animal health, mainly affecting the endocrine system. Toxic monomers have been linked to cancer and reproductive problems. Since many of these chemicals can cross the placenta, harmful effects have been found in newborns via mothers exposed to plastic toxins during their pregnancy. They promote growth retardation and neurological harm in newborns and young children, and hormonal derangements and cancers in children exposed directly to them (Koushal, 2014).

Micro plastics are particularly insidious. Durable, and lightweight, disposed single use plastics such as packaging and sheeting persist in the environment, often reaching the sea, and tending to remain on the surface. Even if plastic does eventually biodegrade, it temporarily breaks down into smaller fragments, which then produce so-called ‘microplastics’, each with its own specific and significant sets of impacts (Koushal, 2014).

Toxins leached from single use plastics such as drinking water bottles and food packaging often end up in water bodies where they continue to leach these harmful chemicals for a very long time. Some of these toxins have been found to cause human male reproductive dysfunction, breast growth and testicular cancers, others estrogenic side effects, premature birth, intrauterine growth retardation, preeclampsia and still birth, yet others seem to lead to insulin resistance and diabetes. We have become so accustomed to the ubiquitous presence of plastic that it is difficult to envision life when woods and metals were the primary materials used for consumer products. Plastic has become prevalent because it is inexpensive and it can be engineered with a wide range of properties (Koushal, 2014).

But plastic waste is a major environmental and public health problem particularly in Latin American, Asian, and African urban areas, where the majority of the world's recycling is often located in slums, done in backyards, and waste dumps. It usually results in the down cycling of plastics into lower-quality materials and objects that have higher and more leachable levels of toxicity, and wastewater with high pollution loads of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) (Narayan, 2001).

The final stage in the life cycle of plastics—disposal—is by burning in incinerators, dumping in landfills, or by simply tossing them out randomly—littering with them. Burning chlorine-containing substances releases toxic heavy metals and noxious dioxins and furans, two of the most toxic and poisonous substances on earth. and can cause a variety of health problems. Ultimately, recycling and degradation of conventional plastics by means of bacteria and fungi may be somewhat helpful. While useful in some applications, biodegradable plastics are not of much use in construction, and in all cases, source reduction—altering the design, manufacture, and use of plastic products and materials—is essential.

4. Discussion

Contemporary discourse prompts us to properly understand the assets of simpler and more robust technologies. The elegant survival of traditional structures found standing amidst the earthquake ruins of modern buildings encourage us not only to re-examine the roots of our cultures for how to build better to protect us from all sorts of calamities, but to build better and healthier for everyday life. The long-term transmission of traditional construction knowledge is a reflection not of "old-fashionedness" but of a commitment to the quality of our culture (Bankoff, 2015).

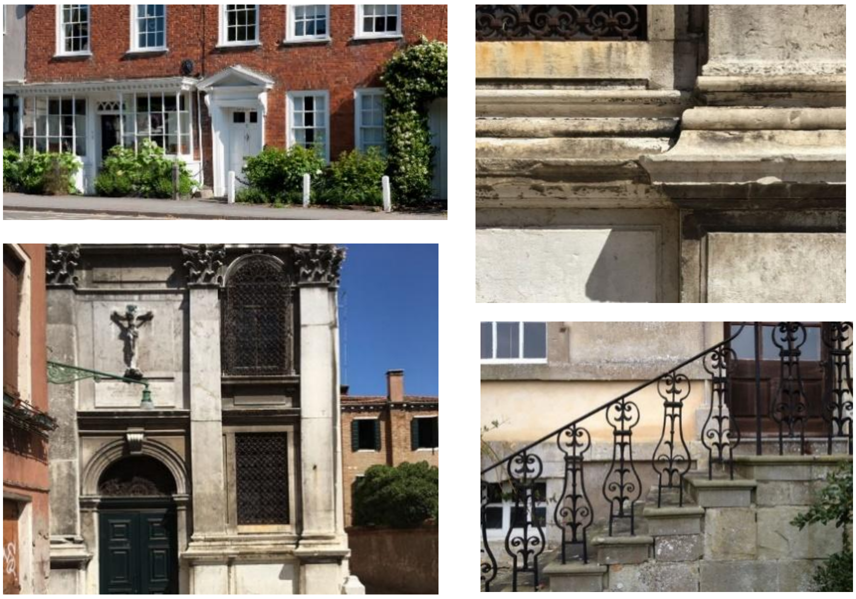

Figure 11. Top left, Brick house in Dedham, Essex, UK. Top right, Stone base and pedestal in Venice. Bottom left, Church façade in Venice. Exterior stairs at Frampton Court, Gloucestershire, UK Images courtesy Francis Terry

We were heartened to see Prince Charles recently making this point during his tour of Australia. There, in an interview with the Australian Financial Review, he shared his delight in the growing awareness of the urgent need to get away from "throwaway society." Giving the example of fashion sustainability, His Royal Highness said, "I have always believed in trying to keep as many of my clothes and shoes going for as long as possible (some go back to 1971 and one jacket to 1969) – through patches and repairs – and in this way I tend to be in fashion once every 25 years…"

The Prince of Wales established the 'Campaign for Wool' in 2010 which encourages the fashion industry to make greater use of natural fibre.

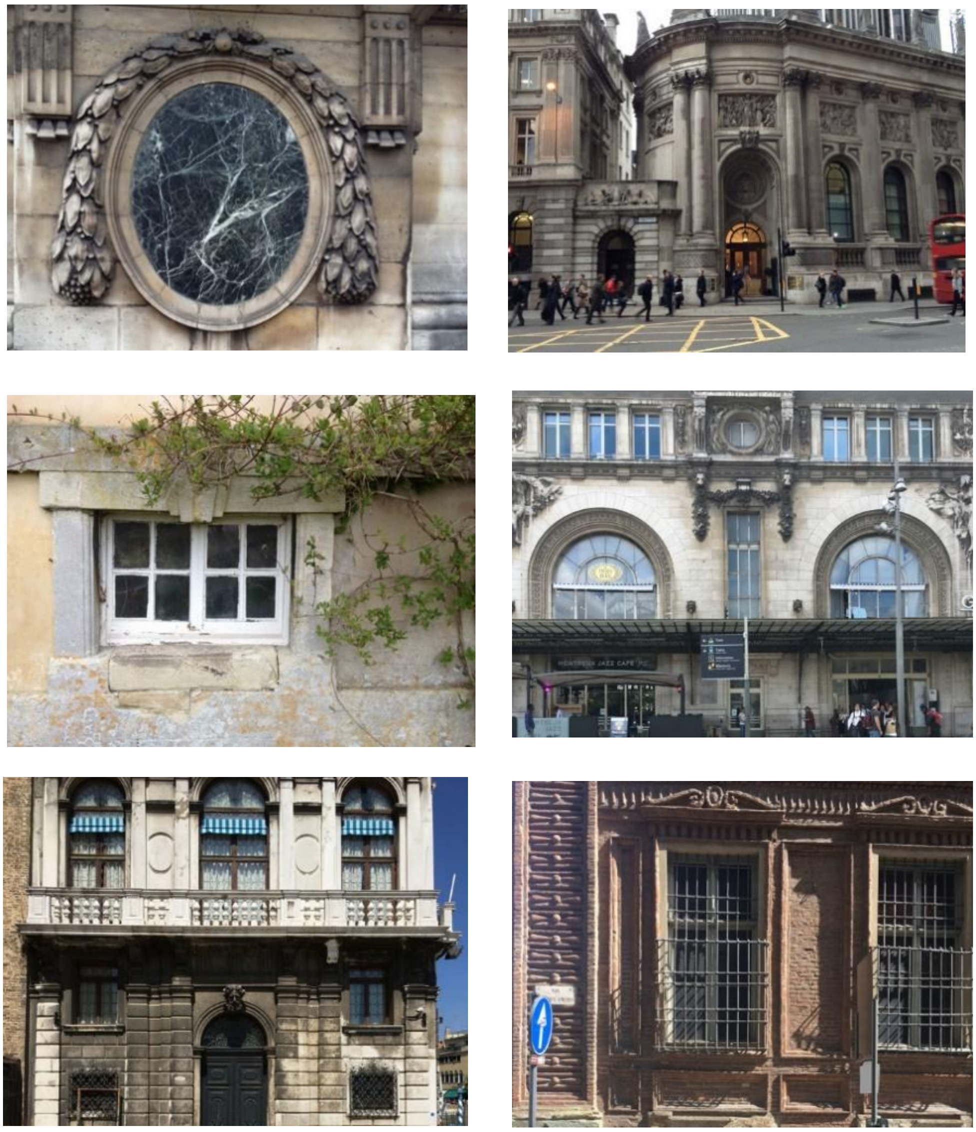

Figure 12. Top left, stone and marble detail in Place de la Concorde, Paris. Top right, stone buildings on Bishopsgate, London. Middle left, Window within stone surround at Frampton Court, Gloucestershire, UK. Bottom left, Stone Palazzo in Venice. Bottom right, The Carignano Palace in Turin. Images courtesy Francis Terry

This argument can also be applied to traditional building materials. A brick, render or stone building improves with time as the weather will stain the facade and erode the sharp edges. Our clients look forward to when the look of the new houses or buildings we have designed for them has softened and mellowed with age. Indeed, old buildings show this ageing process beautifully. Dirt and damage make them more, rather than less, attractive.

The building materials used before the 20th century were brick, clay tiles, stone, slate and timber. Traditionally a wall was made typically of brick with plaster on the inside and that's it.

One of the great aspects of traditional materials is that they are easy to separate and recycle. Stone and brick, if laid in lime mortar, can be easily taken apart and reused. Likewise, slate and clay tiles on roofs which can be simply removed from their timber batons. Timber can be reused or reformed into plywood or burnt as fuel. If timber is left to rot, it will just go back into the ecosystem with no harm done.

Modern construction favours complex constructional systems with a variety of materials. Today a wall may have a weatherproof skin made of metal or plastic, behind this is a thick layer of petrochemical insulation, then a cavity followed by a steel frame with a concrete panelling system. The joining of these materials will have special systems involving further materials like metal or plastic fixings. This makes the recycling of the wall problematic as the materials are hard, if not impossible to separate. The reason why modern walls are so complex is partly down to insulation, which is there to reduce the energy used to heat buildings. But by solving one environmental issue, another crops up.

Increasingly buildings are made from some form of plastic, this could be the windows, doors, insulation, walling and sometimes roofing, in fact, you could probably make a building entirely of plastic, if that was your aim. As plastic starts to fill our oceans, we are starting to see what an environmental disaster plastic is, and are beginning to think of alternatives to petrochemical products.

Figure 13. Two blocks of polystyrene in Suffolk. Courtesy Francis Terry

Plastic does not degrade the same way as traditional materials. On a walk in Suffolk, we came across two blocks of polystyrene, which, when we walked past them a year later, they were still there. Sadly, they will not biologically degrade. As these issues become more dominant, the debates will start informing construction. Making a building plastic free, for example, should at least be an aim or intention for all.

Using hemp or cotton shopping bags is the start of a real change. But this sort of attitude has yet to permeate architecture. We call on architects, whatever their style, to start looking at more natural materials for construction, in the same way that restaurants and food packaging do in often boasting their natural credentials, being free from artificial additives, etc.

5. Conclusion

Although traditional materials and craftsmanship are expensive and out of the price bracket of consumers producing small projects, *based on my experience (the client must remain confidential),* for the same quality project, the construction cost is roughly the same regardless of the technology, materials, or style in projects over 40,000 sf (4,000 m^2). Architecture isn't about making a single meal choice between a battery chicken or an organic free-range hen.

Buildings are lasting products with intense environmental costs – whether in the extraction of their materials or their elimination or recycling after use. A glass wall is an order of magnitude more expensive than a masonry wall with windows. Two low-tech windows, an order of magnitude cheaper than a high-tech window, deliver together the same performance. And the idea that buildings should be air-tight is like living with ones head inside a plastic bag.

To paraphrase a colleague who participated in the July 2019 Traditional Building Conference, given that the Empire state Building was completed almost 90 years ago, does anyone doubt that it will not be with us in another 90 years? More to the point, on the Empire State Building's 180th birthday… will a single building be standing from the current 25 billion-dollar Hudson Yards project?

Why should we assemble buildings out of poor-quality materials and systems, in designs that disconnect from history, culture, and the people that use them?While promoting advances in the use of space, proclaiming the cost effectiveness of structures and supposedly assembling them at mind-boggling speeds, few, how many Modernist structures are of long-term value.

Unfortunately, some Modernist structures promoted on the basis of their innovative use of space become dysfunctional soon after opening. Supposedly cost-effective structures may have remarkably short life spans: and people have always built things quickly when they chose to. The Colosseum in Rome was built in eight years, 72 to 80 AD, including a foundation that straddled an underground river. Perhaps, in a few years' time, the great divide in architecture will not be classical versus modern but rather be plastic versus traditional materials.

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