INTELLIGENT BUILDINGS FOR INTELLIGENT PEOPLE
A CONCEPT

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Abstract: The past decade has seen unparalleled evolution in the field of Materials engineering. Largely due to the unique properties seen in materials in the nanoscale relative to their macroscopic counterparts, nanomaterials as an example can be used to enhance tensile strength, insulation and are biomimicable. These properties combined with integrated structural monitoring and diagnostics systems are set to revolutionize the construction industry. Current research shows the inclusion of self healing properties, bringing these endeavors full cycle.

Structural integrity is a key facet of building maintenance which historically has been evaluated on the basis of empirical studies stemming from lifecycle analysis of the concerned structure. The associated costs, lead times and lost revenue due to these activities can be mitigated by using materials which are engineered to report the parameters of concern to building monitoring systems. These systems can be the resultant of nanocomposite materials which are self organizing in nature, in turn forming interrogation capable grids. Dielectric and complex impedance measurements of these grids will be sampled through an analog to digital conversion interface linking the captured data on to the building management system. Alerts can be issued in real time when material boundaries are crossed, indicating impeding structural changes. Constants associated with the nanocomposite materials will set the thresholds for the alerts. The captured raw data would have the ability to monitor parameters such as vibration, stress/stain (piezoelectric materials) and thermal gradients (temperature coefficient of complex impedance).

Furthermore, materials such as TiO2 facilitate photocatalysis, where the free radicals can be used for the oxidization of organic matter resulting in self cleaning surfaces. Anatase titanium dioxide can also be used in the form of a composite addition to cement for Bio mimicking structures to be used to offset our carbon footprint. Although yields of such activities remain low, the research too is in its infancy. By monitoring the redox reactions of these materials in the form mentioned above, it will be possible to observe the conversion efficiency as live “heat map”, resulting in much needed empirical data. Reportedly, the use of TiO2 has been used to control the growth of biological matter. As deterioration of structures due to biological matter is immense, these properties will allow for the control and monitoring of the design and environmental parameters which facilitate their growth.

Macroscopically the construction industry is poised to benefit greatly by these immediate changes that nanotechnology has brought to the materials engineering. Resultant structures would encompass the low carbon footprint which is expected and sought after in the current climate as well as the economic and safety benefits inherent of such activities.

This paper reviews a range of concepts and technologies capable of harmonizing built environment and the state of the art in monitoring and energy capture.

1. Introduction

Individual components of a building can be taken in to consideration due to their placement and thus its inherent potential. The Foundation, Frame, Bulk material, Windows/doors, Floors, Roof and Skin can contribute to 2^{nd} order activities while maintaining its core role through the use of intelligent materials. The 2^{nd} order activities can be identified in two logical and complimentary groups being sensing and energy scavenging. Sensing and Energy scavenging in built environment can be carried out either through the use of intelligent materials which are symbiotic in nature or through the use of components added on to the structure.

2. Concepts and Technology

As an example, an intelligent foundation could implemented either through the use of a ZnO (piezoelectric) coating on the steel bars in the reinforced concrete which would sense the stress strain and sheer components, likewise these properties could also be sensed through the integration of an almost off the shelf optical fibre (Fibre Bragg Grating) sensors which can be mounted on the surface. Geothermal electrical energy generation becomes feasible as the building becomes taller, due to the requirement of a deeper foundation. Further enhancement of the thermal gradient is possible due to the colder environment at higher altitudes enabling faster heat dissipation. Buildings of lower height can also benefit from geothermal energy generation in the form of thermal energy for heating. These vary in terms of economic viability as a 2007 study indicates a break–even price of 0.04-0.10 € per kW·h [i], at a capital expenditure of 2-5 million € per MW of electrical capacity. Expanding on the concept, the ability to capture the heat energy through solar concentrators on the roof and store it for night time use is a further possibility through the use of borehole thermal energy storage. It is a system where an underground structure is used for storing large quantities of solar heat collected in summer for use later in winter. A key concern in power generation, regardless of the source of the energy is providing a consistent output. Hence, the use of an underground heat storage facility would provide a future proof and cost effective mechanism for medium to large scale energy storage.

The structure of a high rise building is predominantly made of steel. Piezoelectric materials mixed composites would allow the building management system to monitor a life stress/strain map of the entire metal structure. The taller the buildings are there exists a slight sway due to the wind factor at the top of the building. These intelligent frames are well placed to monitor the structural rigidity and health of a building during the course of an earthquake, storm or even a manmade disaster such as an explosive device detonating.

Thus situational awareness pertaining to the building would become instantly available to emergency or rescue workers. These material based sensors would allow for early warning for such natural disasters as earthquakes much earlier due to the depth of foundation structure. Likewise costs associated with building maintenance can further be mitigated since real time data is always available. Standard steel based structures can be monitored through the use of Magnetoquasistatic Sensing such as the Meandering Winding Magnetometer. It is inductive sensing using magnetic fields to monitor changes in the properties of magnetic and/or conducting materials such as metals[ii]. A piezoelectric coating or the inclusion of a piezoelectric compound in to the metal structure would allow for power generation due to the inherent sway in larger buildings. This would further complement the carbon footprint of the building. Strategically constructed wind tunnels through a high rise building have been demonstrated to generate significant amounts of electricity. Such activities are currently shifting from the conceptual stages to realization.

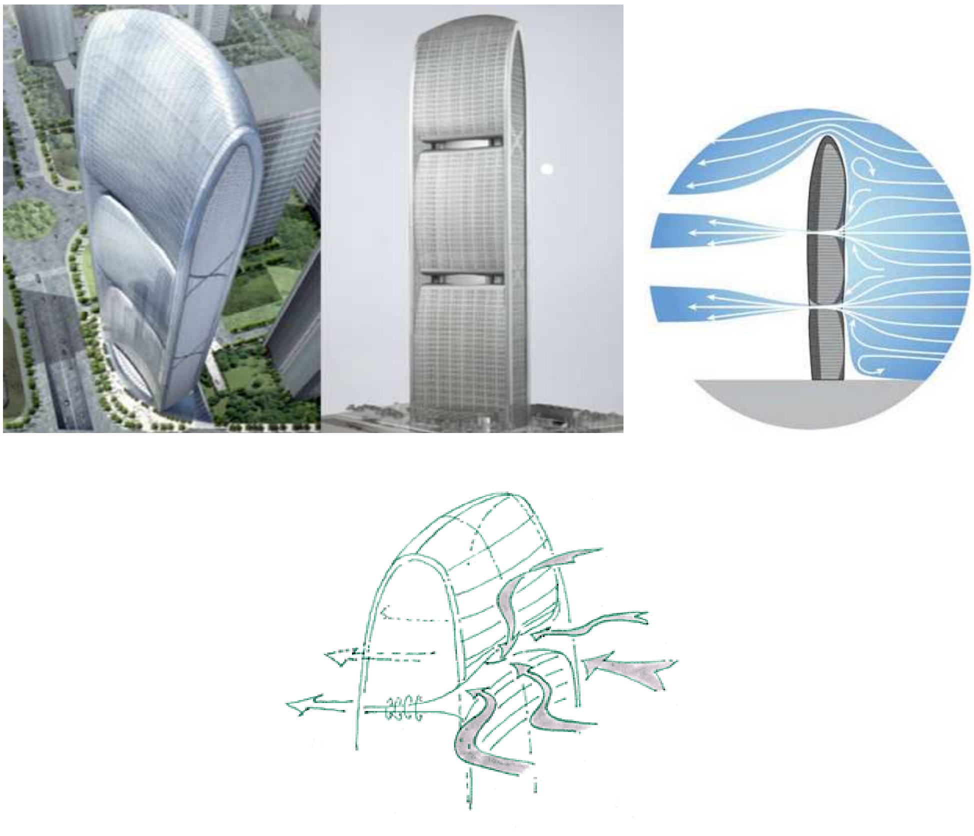

Fig. 1: Pearl River Tower Wind turbine concept (Skidmore, Owings and Merrill)

Bulk building material such as concrete can be modified through conducive fiber compounds for a sensing ability is associated with the reversible change of the electrical resistance of the concrete upon deformation[iii] in the elastic regime. It allows a further aspect in the monitoring of the structural rigidity of the building. Loading due to machinery in large buildings can be analyzed through such sensing mechanism. Since stress is force per unit area, stress relates to force. Hence, the smart concrete can serve as a scale for weighing.

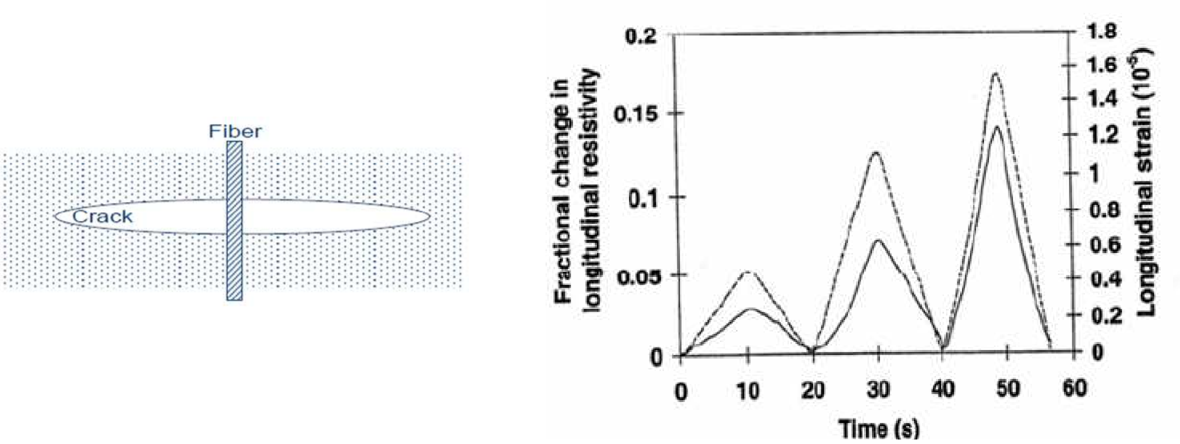

Fig. 2: Smart concrete[iv]

Orifices such as doors and windows can be utilized through the use of nanotechnology based spray on solar cells to generate electricity throughout the day. Such films are at the research stage currently where proofs of concepts have been developed[v]. The use of electrochromic material to automatically attenuate the solar irradiance in to the building can help mitigate air conditioning costs during the summer and heat loss during the winter period. Furthermore liquid crystal displays can be built on to the surface of the windows to allow them to be used as display for the building health data harnessed from the sensors discussed thus far. Another interesting application is the addition of an Organic LED on the surface of each of the outside facing windows of the building to create large scale bill board like structures. The use of transparent electroluminescent materials would convert the simple window in to a multifunctional interface device.

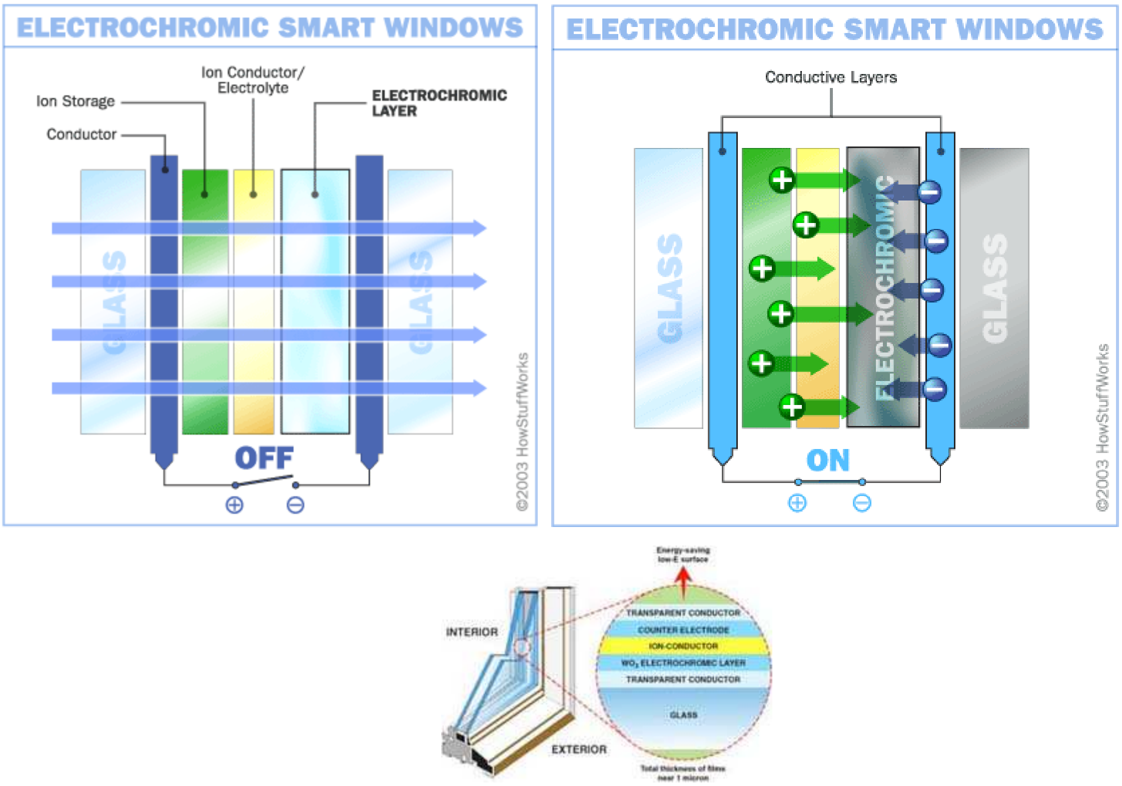

Fig. 3: Electro chromatic window [vi]

Floors are well suited for energy scavenging as it sees continuous use throughout the day in the form of walking which results in vibration energy. Piezoelectric flooring has been demonstrated to be able to harvest this form of energy[vii]. Especially areas which see many visitors such as the entrance or the lounge areas are very well suited to this technology. Concentrated areas of high levels of lateral displacement such as staircases are yet another area were this technology can be implemented. It would also allow for smart cleaning of the building taking in to consideration the level of exposure it has seen to foot traffic.

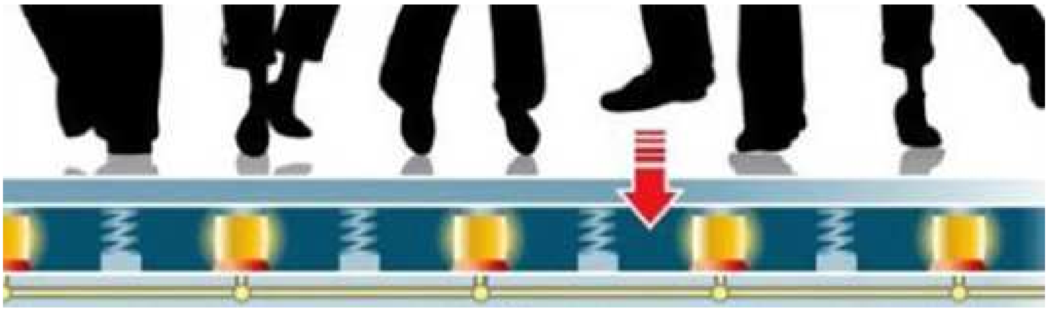

Fig. 4: Piezoelectric floor

The roofing area can be used for solar energy capture at a higher efficiency than the windows of the building. It can be achieved through the use of fresnel lenses (solar concentrators) to greatly enhance the cost effectiveness of solar cell based energy generation. Further maximizing the roof area, the solar cell back plane can be cooled through a heat exchanger which itself will be generating second order energy. Air quality monitoring at gradual elevations would provide valuable data with regards to smog levels and their height above the city. Along with the ability to detect contaminants such as ash from volcanic activity and to map the propagation dynamics.

Paints used in the construction industry are predominantly are based on a TiO_2 filler. TiO2 facilitate photocatalysis, where the free radicals can be used for the oxidization of organic matter resulting in self cleaning surfaces. anatase titanium dioxide can also be used in the form of a composite addition to cement for Bio mimicking structures to be used to offset our carbon footprint.

3. Conclusion

Major breakthroughs in material sciences have allowed us to actively persue green applications in built environment. The benefits are twofold, resultant being self aware and self sustaining buildings. The concepts approached in this paper should be approached at the inception of such projects as it is essentially the bottom up nature which results in a synergy to the structure. Furthermore integration at the scale discussed allow for higher efficiencies in sensing as well as energy generation and conversion. Approaching each element of a building structure has allowed the location and properties inherent to the Foundation, Frame, Bulk material, Windows/doors, Floors, Roof and Skin to be taken in to consideration for relevant enhancement of the overall goal of achieving a intelligent, self sustaining building.

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