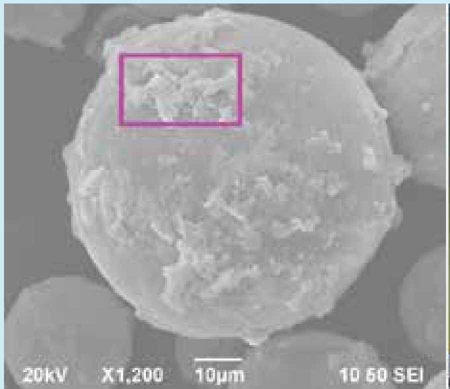
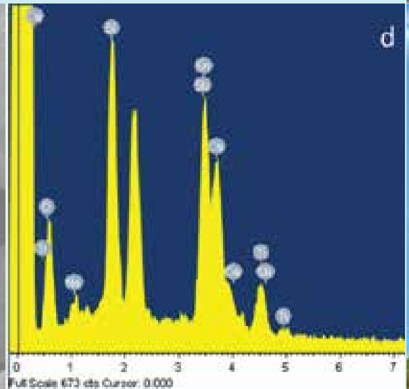
Outcomes of a Collaborative Research Programme with the Construction Industry Part III





MARCH 2017

PolyU
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

FACULTY OF CONSTRUCTION AND ENVIRONMENT
建設及環境學院

CONTENTS

Foreword

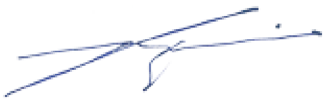
This Executive Summary Report, intended for Construction Industry Leaders, has been produced to provide a measure of feedback to the Industry on the use of its money. Part of the costs of the research reported here was provided by Hong Kong construction industry firms, indirectly, via the now defunct Construction Industry Institute-Hong Kong (CII-HK).

Launched in 2009, the CII-HK/PolyU Innovation fund was established to support 25 research projects of relevance to industry in Hong Kong. The first 11 were reported in March 2015, in Part I of this document and the next 8, in Part II, in March 2016. Of the 6 remaining projects, 4 were completed during 2016 and 2 will finish within the next few months. All 6 are reported in Part III, the final part, of this document.

The impetus for the fund derived from a CII-HK closing down donation of HK$ 4 million which the Faculty matched with a further 4 million.

The 6 projects below, diverse in nature, are concerned with a) stone cladding panel anchorages and the effect on sensitive equipment of construction noise vibrations and b) four environmental sustainability projects relating to carbon emissions performance, green building delivery transaction costs, large vertical axis wind turbines and a novel insulating wall material.

Like the previous two reports, I hope this one will stimulate industry to continue working with us. The Faculty itself and the University's Research Institute for Sustainable Urban Development (RISUD) prefer to work with industry whenever possible.



Ir Professor You-Lin Xu
Dean
Faculty of Construction and Environment
The Hong Kong Polytechnic University

March 2017

Introduction to the Research Programme

Background

In 2009, the Faculty of Construction and Land Use (now known as the Faculty of Construction and Environment, FCE) created the Construction Industry Institute (Hong Kong)/ PolyU Innovation Fund to encourage collaboration in research and innovation between the construction industry and the Faculty.

Half of the HK$ 8 million in funding was from FCE and half was a closing down CII-HK donation. CII-HK had always existed to promote Industry –University research collaboration, inspired by the 2001 Construction Industry Review Committee's recommendations. The establishment of the CIC (Construction Industry Council), however, which developed its own procedures for funding such collaboration, effectively duplicated the role of CII-HK. The funds held by CII-HK were then distributed among those universities in Hong Kong which undertook construction research. PolyU received HK$ 4 million.

The decision was made to use the CII-HK/PolyU Innovation Fund to fund projects lasting approximately two years with a maximum for each one of HK$ 300,000.

Ir Professor JG Teng

The Research Programme

The 6 projects below belong to the third batch funded. The first batch, of 11, was reported in Part I, and the second, of 8, in Part II, in March 2015 and March 2016, respectively. The money spent on these final 6 projects was HK$ 1.8 million.

The 6 projects are quite diverse in nature, with two covering a) a new type of anchorage for stone cladding panels and b) protecting sensitive facilities against ground borne construction induced vibrations. The other four projects all relate to environmental sustainability, namely, carbon emissions reduction indicators, 'green building' delivery transaction costs, the structural performance of an actual large vertical axis wind turbine and a novel solar heat reflecting insulating material.

The projects are strongly linked to practical application, in line with a cornerstone policy of the University and its Research Institute of Sustainable Urban Environment.

Ir Professor JM Ko

The Purpose of the Report

The report is written principally for leaders in the construction industry to provide feedback on the use of funds provided by the industry. The aim was to write in plain language. The report contains technical terms, only to the extent they would be commonly understood by persons familiar with construction.

Each project includes an outline summary of why the project was undertaken and its findings. Appendix 2 references the papers published, for the benefit of those who might want to follow up in more depth. This list is in embryo form only at this early stage. The appropriate Principal Investigator should be contacted for further information if necessary.

Dr Jian-guo Dai (Project 1)

Dr Jian-guo Dai
Associate Professor
Department of Civil &
Environmental Engineering

Dr Dai has wide interests in technologies related to civil engineering and building structures. These include fibre reinforced polymer engineering applications, questions of the durability of concrete in hostile marine environments, advanced structural composites and the building exterior cladding solutions. He is a Vice President of the International Institute for FRP and the Chairman of the Technical Board of the Asian Concrete Federation.

Exterior wall stone cladding systems currently used, comprise a metal frame anchored to a building's exterior wall with individual panels dry fixed to that frame. This is expensive, and risky in the case of fire, since the metal frames will soften at high temperatures. In this project, a system has been developed whereby the stone panels themselves comprise the outer, permanent, formwork of the in-situ concrete exterior wall. For bonding, each panel has a 'key' cut into its inside face. The system is safer in the case of fire, is cheaper, and provides a more durable reduced maintenance wall.

Professor Edwin Chan (Projects 2 & 3)

Professor Edwin Chan
Professor
Department of Building and
Real Estate

Professor Chan, unusually broad in his range of expertise, is a fully qualified architect, barrister and surveyor. His research interests lie in planning and urban development, to which all three professional specialisms are relevant. For many years now his research has been focused on sustainable development issues related to buildings and urban development, with many papers published. He is active in Hong Kong serving professional bodies, and a number of government boards and committees including the Town Planning Board and the Housing Authority.

a) The project addressed the issue of carbon emissions by buildings; the need for a commonly agreed index measure for use internationally, along with data bases of actual emissions to help with the setting of targets. Based on the literature, that index should be "*average emissions per unit of working floor area pa*". Carbon emissions accrue at all stages, from inception to demolition, but a consensus exists that the 'building in use' stage is the biggest contributor. The team demonstrated a method for assessing emissions sensitivity to different values of the many possible office building design parameters.

b) The team is studying the costs involved in delivering energy efficient 'green buildings'. Green building delivery 'transaction costs' are being identified by the team, classified, and their relative levels of significance deduced. It is clear we must reduce the use of energy in our buildings if Hong Kong is really going to reduce its energy use by 2030 to 75% of its 2005 figure. The technical means are well understood but progress is very slow. Market forces are clearly insufficient, and government incentives are required. A thorough appreciation of the scale and nature of the extra transaction costs is fundamental, if government incentive schemes are to be truly effective.

Professor Hongxing Yang (Project 4)

Professor Hongxing Yang
Professor
Department of Building Services Engineering

Professor Yang has spent more than 30 years in renewable energy research in mainland China, the UK, and Hong Kong. He leads the Renewable Energy Research Group within the University's Research Institute of Sustainable Urban Development. He is active, too, in advanced materials research as it relates to saving energy in buildings. His team is expert in wind, solar and ground heat sources of energy, including new solar photovoltaic technologies, vertical axis wind turbines, concrete foundation piles as ground heat exchangers, and new insulating coating materials.

The team has developed self-cleaning high insulation coatings for exterior walls to help reduce building energy needs. The coating consists of hollow glass microspheres, a low conduction/convection component, closely dispersed within a binder containing titanium oxide, a good reflector of Infra-red radiation. The coatings can effectively decrease wall U-values of buildings. Other components enable a hydrophobic coating to be produced on the one hand and a hydrophilic coating on the other. The former is suitable for dry climates because contaminant-bearing water vapour droplets find it hard to 'stick' to the surface. The latter for damp/wet climates because droplets have such a flat contact angle that they slide off very easily.

Professor You-Lin Xu (Project 5)

Professor You-Lin Xu
Dean
Faculty of Construction and Environment

Professor Xu, Dean of the Faculty of Construction and Environment at The Hong Kong Polytechnic University and recipient of a Croucher Foundation Senior Research Fellowship, is an expert in *smart structures*, i.e. in long term real time structural health monitoring and control. He has worked on a number of large buildings and long span bridges in China, including the new CCTV tower in Beijing. He has also studied the structural and vibrational behaviour of the Tsing Ma and Stonecutters bridges in Hong Kong. Over 250 SCI papers attribute to his contribution to the development of smart structures technologies.

The PI is expert in 'smart structures' as usually applied to major bridges and very tall buildings. A smart structure synthesizes control features and structural health monitoring via instrumentation strategically distributed throughout the structure. This expertise was applied to a vertical axis wind turbine built by Hopewell Holdings in Guangdong. Even though horizontal axis turbines dominate the commercial scene, there are good structural cost and fatigue reasons not to write off the vertical axis turbine for all time. The concept of the *smart VAWT* was implemented and performance data obtained in relation to the necessary continuous control of blade pitch angle.

Dr Songye Zhu (Project 6)

Dr Songye Zhu
Associate Professor
Department of Civil &
Environmental Engineering

Dr Zhu is a structural engineer, who joined The Hong Kong Polytechnic University in 2008, following degrees from Tongji University in China, and Lehigh University in the USA. His research promotes advanced structural engineering technologies, which includes the monitoring and interpretation of vibrations in structures.

Data was provided on the vibrations inside a health care building, near very sensitive equipment, due to mini-piling and vibratory sheet piling adjacent to the building. Site piling had been forbidden for several hours during the day, but the research results showed that a mini-piling rig could be operated at any time, as long as it drilled at depths below 6m and was at least 10m from the building. This data allowed a construction cost saving of 2 million HKD.

A new hardware/software system was created for general use anywhere, enabling the vibrations inside a building to be monitored in real time and an alarm set off if a pre-set value is exceeded.

1. An Innovative Stone Cladding Anchorage System for Buildings

Background and Objectives

The external decoration of buildings with stonework panels is a very popular technology in building construction. The annual consumption of stone cladding is more than 30 million square metres in Hong Kong and mainland China. The stone panels are conventional units of a “dry fastening stone cladding system” whereby a metal frame (usually stainless steel) is anchored to the structural wall of the building and a dry fastening element, fixed to the frame, connects with the inside of the stone panel. The dry fastening stone cladding system has advantages over adhesively bonded stone. In the latter case, panels can become unbonded and fall off the building, endangering people below. However, the former is much more expensive due to the stainless steel metal frames and fixtures. In addition, the fire performance of dry fastening stone cladding systems is of great concern because the metal frames supporting the stone panels may soften quickly if temperatures become too high. The cladding system is liable to collapse under these circumstances, producing “stone rainfall” and threatening the safety of pedestrians as well as making firefighting and rescue activities more difficult.

During this project, an innovatively anchored stone cladding system was developed. In the new system, the stone panel acts as permanent formwork for the cast concrete of the main structural wall. The inner side of the stone panel contains dovetailed grooves (Fig.1), which act as shear connectors between the stone panel and the hardened in situ concrete. The ‘anchor’ is for tying the cladding panel to reinforcement bars, which is necessary to resist the pressure of the in-situ concrete before it sets. There are joint connections between adjacent stone panels to prevent water penetration and to seal the cladding (Fig.1).

The new stone cladding system has many advantages over the existing dry fastening system: (1) there is no need for metal frames, bringing a significant reduction in cost and reducing fire damage risk; (2) the stone panel is permanently anchored to the structural concrete, prolonging the service life of the cladding; (3) the stone cladding provides protection to the concrete structure, significantly enhancing structural durability and sustainability; (4) the shear connectors prevent any spalling/falling off of stone panels, (5) the usable space of the whole structure is increased; and (6) construction duration is shortened because façade installation and concrete wall casting become one single operation, integrating structural and architectural design.

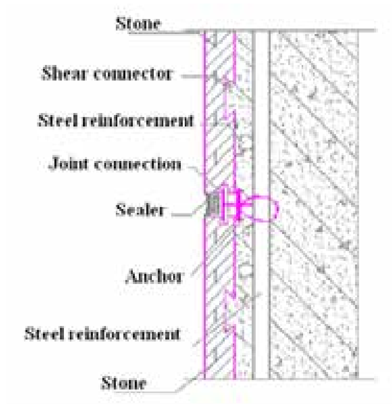


Fig.1 New stone façade system

Experimental Program and Findings

The mechanical performance and durability of the dovetail key, bonding the grooved stone panel to the concrete wall were studied through experimental tests in the laboratory (Fig.3). Finite element (FE) analyses were also conducted to optimize the dovetail size and shape details (Fig.2), to explore different failure modes and the corresponding dovetail key anchorage capacities. It was found that the new stone façade system can fail in either the stone of the panel or in the concrete, depending on the type of test, but the anchorage capacity is usually higher than 40 tons per square metres, which is much larger than needed to resist assumed design loads. Full-scale in-situ tests were also conducted on a building frame in Shenzhen city to demonstrate the reliability of the proposed stone façade system, (Fig.2), leading to the conclusion that the stone façade system can achieve the same service life as the wall concrete itself, without the maintenance concerns associated with the durability of metal frames. The success of the tests was witnessed by many design institutes, contractors, universities and government authorities. Through the close collaboration between PolyU and industry partners, the validity of this new stone façade system was also demonstrated on a small practical project in Shenzhen city (Fig.4).

(The financial support from KEI CHEONG ENGINEERING CO. LTD is gratefully acknowledged.)

Project Outcomes

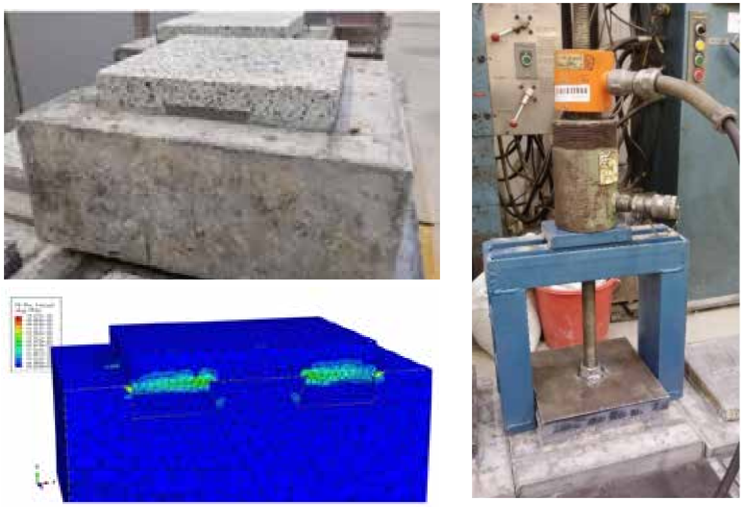


Fig.2 Anchorage capacity of the new stone façade system: laboratory tests and finite element analysis

Fig.3 In-situ pull-off tests of the new stone façade system

The outcomes arising from this project have been well recognized by the China High-Tech Industrialization Association (Fig.5). As a further step, the reliability of the stone façade system under seismic loading is currently under investigation. Integrating the proposed stone façade system with the building insulation system has also been explored. The research achievements will be reflected in the technical guidelines “Decorative Building Cladding System”, which is under development by the Ministry of Housing and Urban-Rural Development of China.

In summary, this project has led to a more durable, economic and safer stone cladding system that promotes more sustainable building construction. The system meets the urgent need to increase industrialized building construction. It has great potential for applications in Hong Kong, mainland China and the rest of the world. Interested persons can contact Dr Jian-Guo Dai at cejgdai@polyu.edu.hk

Fig.4 A small demonstration project at Shenzhen

科学技术成果证书

经审查核实“饰面混凝土墙体材料及复合技术（简称：复合装饰混凝土）”被确认为科学技术成果，特发此证。

Fig.5 Recognition from the China High-Tech Industrialization Association

2. Indicators of Low Carbon Emissions Performance for Office Buildings

The Need for the Study

Across the world, no agreement exists on what indicators to use when comparing the carbon emissions of whole countries, regions, cities, urban regions, housing estates right down to individual buildings. The lack of agreed sets of indicators for use at different levels inhibits progress. One study cannot be adequately compared with another. Macro level indicator comparisons are important for assessing the scale of the overall carbon emissions problem and how the problem varies in scale around the globe. Thus we know that construction, finished buildings, and infrastructure are responsible for over a half of global carbon emissions. Macro level indicators, however, are of little help in telling us how to reduce carbon emissions.

The research team, after considerable study, decided that the ability to accurately compare the carbon emissions for individual buildings was fundamental and that the indicator of choice for all to use should be the Average Carbon Emissions per unit area of working area in the building per annum. The total neighbourhood, city, regional and indeed national carbon emissions due to buildings, is simply the sum for all individual buildings. Carbon emissions, of course, are related to energy demand via a *fuel source factor* depending on the type of fuel/renewable source applying to the building.

That indicator of choice above is simply stated but not simply implemented. Carbon emissions calculation methods would need to be standardized (these would vary between building types) and data bases established for each building in operation, if accurate life cycle estimates are to be made. One of the practical difficulties is the availability of accurate data. For a city such as Hong Kong, it is conceivable that progress towards standardization could be made.

The energy consumed by a building is as follows:

a) that involved in extracting the raw materials from the ground

b) that required to convert those materials into elements/materials (such as concrete, steel sections, earthenware items, timber sheets)

c) that required for construction on site, i.e. transport to, and assembly of products ‘b’ into finished buildings

d) that consumed during its lifetime, in serving its intended functions and

e) that expended at the end of useful life during demolition and wastes removal

Of these five, the largest contributor is ‘d’, by common consent of those studying carbon emissions. The team therefore, as a first step, developed a simplified assessment model for evaluating carbon emissions at the design stage, restricting the scope to that of multi-storey office building. Specifically, how the energy demand might most practically be calculated in terms of the following five sets of parameters: building layout parameters, building envelope parameters, interior space condition parameters, A/C plant specification parameters and occupant behavioural parameters in relation to thermal comfort. What more detailed parameters to include and, importantly, the sensitivity of the energy demand to the chosen parameter values were all components of the study.

The five sets of parameters above became 21 individual design parameters. Many of these parameters were given a range of possible values. All values in the range were assumed to be equally likely.

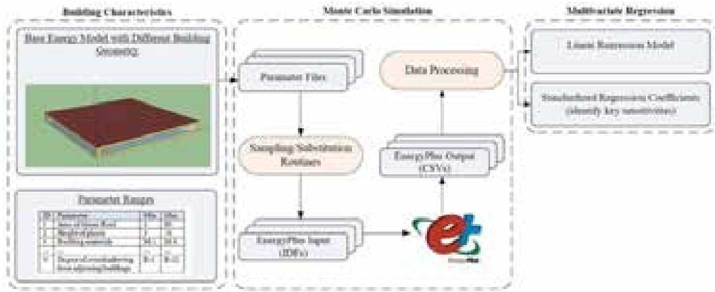
Project Outcomes

To compare the contributions to environmental sustainability of different building designs, the influence of each of these 21 parameters on energy usage was assessed. This influence was usually calculated by multiplying a *parameter constant by a quantity(s)* representing the “magnitude” of the parameter. Thus for a given type and thickness of window glass, the parameter constant is the insulation U-value for the type of window concerned. The three relevant quantities are ‘window area (sq.m.)’ coupled with ‘difference in air temperature inside and outside (°C)’ coupled with ‘time (sec.)’ Thus, for a 1-hour time interval, an estimate of the cooling energy required, is ‘U x the total area of window x the assumed average temperature difference between outside and inside x 3600’. Many parameters are of the above type. The window/wall parameter, however, is simply a ratio, which indirectly affects the cooling energy required. The ‘ventilation’ input parameter is simply a number, the number of air changes per hour.

The software system *EnergyPlus* was used for calculating energy demand for any building under design, as expressed by values for the 21 parameters. A large number of designs were simulated by simply making successive runs with a different set of parameter values. In fact, a Monte Carlo simulation approach was adopted. For those parameters with a given range of possible values, a random number would be generated on each run for each parameter (i.e. a ‘dice’ was thrown) and the parameter value selected would be determined by that random number. Thus, a large number of energy demand predictions were obtained for a range of possible designs.

80% of these results were used by *multi-regression modelling software* to form a linear relationship connecting output building energy demand to the sum of the values of each of the 21 parameters multiplied by a coefficient unique to that parameter. The regression software calculated these coefficients. The remaining 20% of the results were then used to check the new model predictions as a means of validating the model. This check was successfully made, implying that the 20% was indeed representative of the 80% and that the 80% was a big enough sample on which to base the regression model in the first place.

The study found that the parameter *Mean Annual Occupancy Rate* most influenced energy demand per unit of useable floor area. The next three in importance are *A/C Equipment Load, Lighting Provision, and Chiller Coefficient of Performance*. This finding is consistent with other studies that showed electrical and mechanical (E&M) equipment/systems are key contributors to carbon emissions during building operation. Apart from that, further attention must be paid to those passive building design parameters *Depth of Perimeter Zone, Window-Wall ratio and typical floor areas*. Although these passive design parameters are less influential than E&M related parameters on carbon emissions, they must be taken into account at the design stage. They cannot easily be changed once the building is completed. In fact, over a 50-year life cycle, say, passive parameter design decisions are very significant in relation to carbon emissions. A balance must be struck between carbon emissions and design aesthetics in the pursuit of environmentally sustainable buildings.



3. Quantifying Transaction Costs for Green Buildings Delivery

Introduction

In Hong Kong, buildings use up to about 80% of the electricity generated and greenhouse gas emissions are nearing 50 million tonnes per annum and rising. By the year 2030, the city seeks to reduce this to only 75% of the 2005 level of 44.8 million tonnes.

In fact, it has been clear for very many years that a) we must reduce our building, cooling, heating and lighting loads and b) that the technical means for doing this are well understood and have been entirely practical in architectural and engineering terms, also for very many years. Much of the research to date has been concerned with how best to design buildings to reduce energy needs and with the efficiency of the installed building services plant, including the associated diagnostics and control systems and with retrofitted solutions for already existing buildings. It has been estimated that building energy efficiency (BEE) ought to be 30% less already than it actually is.

In Hong Kong, progress towards this green building goal is very slow, such that in 2016, emissions are still well above the 2005 levels as indicated above.

The Research Study

This research study, still on-going, focuses on the priority need to understand those societal, market, economic and industry culture factors etc. which are inhibiting green building development, i.e. the focus is on *why* progress is slow. The team's basic hypothesis states that, compared with conventional building, green building involves many additional (transaction) costs in both the procurement and operational stages that are difficult to measure and that this fact is compounded by the additional risks inevitably associated with the unfamiliar. Since market forces are clearly failing to generate a sufficient demand for green building, government incentives are necessary, such as that already in place with the provision of extra gross floor area (GFA) for a green building.

The team's main objective at this stage is to identify the full range of specific transaction costs, classify them and attempt a significance ranking. There is little, if any, understanding within society and the construction industry, that such an analysis is of fundamental importance to the progress for green building. Once an understanding of the transaction costs for green building implementation is acquired, it should be possible to devise incentive policies that can expedite the rate of progress in BEE.

Concentrating on the residential market only, the team adopted a simple interview methodology. So far, more than 30 professionals including architects, engineers, planners etc. in different types of organizations etc. have been asked to identify, and as far as possible, quantify, the extra problems and activities they experience when working on a green building as compared to a conventional building.

Project Outcomes

The Results So Far

The following six types of transaction costs, extra to those for conventional building, have been identified from the interviews:

Search costs: getting updated with information related to green materials and building design.

Research/Learning costs: the extra attention to be paid to market analyses and decision making.

Negotiating/Communicating costs: arising from the processes of environmental grading certification through such as HK-Beam, as well as extra time involved in design because of extra building complexity.

Approvals costs: government approvals often take longer and require modifications from original intentions.

Monitoring costs: known to be high, confirming a large Singapore study, this refers to policy compliance, contract implementation and required outcomes.

Verifications costs: refers to the effectiveness of green materials and equipment. Often extra to normal compliance testing is required for example.

The following diagram ranks these six categories in order of significance and shows their relative levels of importance.

Priorities with respect to:		Combined
Goal: Transaction Costs		
Monitoring Cost	.236	
Approval Cost	.217	
Negotiation/Coordination Cost	.206	
Verification Cost	.161	
Research/Learning Cost	.091	
Information Searching Cost	.088	
Inconsistency = 0.00517		
with 0 missing judgments.		

4. Novel Solar Heat Reflective Insulating Materials

Introduction

This project mainly improves the heat-insulating properties of the building envelope to reduce heat gain and the energy consumed by the air conditioning system.

A packed assemblage of hollow glass microspheres (HGM) makes a very good insulating material because the wall thickness of the tiny spheres averages only 5% of their diameters and the volume of enclosed air is therefore large. Air, of course, is a very poor conductor of heat.

HGM has insulation applications in many fields already. Fully packed microspheres are also light in weight, at $0.2 g/cm^3$.

In the search for new ways of insulating buildings to save energy and contribute to sustainable development, the study team explored ways of making HGM into a paste which could be applied to the external walls of buildings. In fact, HGM alone, reduces only heat transfer by conduction and convection. Radiative heat transfer still takes place. The special HGM coatings the team explored, at nano-scale, themselves possess properties which help to reduce radiative heat gain through the wall and, as it happens, can also possess self-cleansing properties, enabling longer term HGM effectiveness. There has been only a little work in the field by others.

Developing HGM with low IR transmittance has its problems. Methods by others requiring high temperatures were time consuming and produced coatings which varied in consistency. The method devised by the study team, in contrast, is quicker, cheaper, and produces coatings of consistent quality. It looks to be suitable for trials on a larger scale.

The HGM Coatings

Type A coatings: HGM particles were coated with two layers. These add marginally to the thermal conductivity of pure HGM, but more than compensate by reducing radiation heating effects. The compound of the two layers first reflects 19.6 % of incidental light and then strongly absorbs the infra-red passing on. The 70% transmittance of pure HGM can be reduced to about 7% by the additional coatings.

The first, inner, layer is a novel antimony doped tin oxide (ATO). This material largely prevents the transmittance of infra-red (IR) light, thereby reducing radiated heat gain. The second, outermost, layer consists of TiO_2. Titanium oxide has good light-reflecting properties, so incidental light is partly reflected. Most of the IR portion not reflected by the second layer is largely absorbed by the ATO.

The complete HGM type A paste, therefore, protects against both heat conduction and radiated heat transfers.

A 'bonus' property was discovered. The outermost TiO_2 layer is anatase, which has super-hydrophilic properties. Hydrophilic means literally 'water-loving'. Water droplets sit 'flatter 'on the material and are more wetting. In this case with a contact angle as low as 8°. The normal contact angle with HGM glass is about 57°. The type A paste, as well as a good insulator, therefore, is self-cleansing to a certain extent because the water slides away very easily, taking any entrained contaminants with it.

Type B coatings: As an alternative to the hydrophilic first layer of the Type A coating, a super-hydrophobic HGM coating material was also developed. A super-hydrophobic (literally 'water-hating') material, causes water droplets sitting on the surface to be almost wholly spherical in appearance. The droplet contact angle with the material developed is 153°, so there is only a very small force of surface tension attraction between the droplet and the surface. The contaminants carried within water droplets are much less likely to settle. Those that do are easily blown away. A type B coating still contains the second, light-reflecting, TiO_2 layer of the Type A coating, together with this hydrophobic coating.

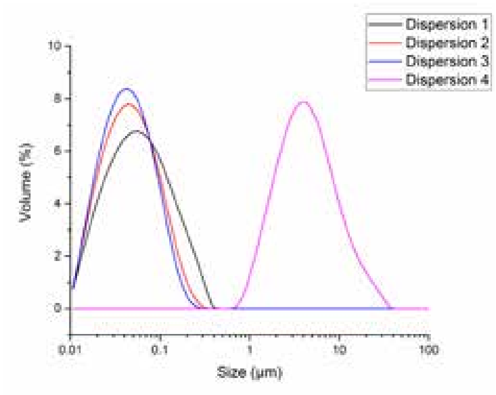
Project Outcomes

Both hydrophilic and hydrophobic surfaces can be defined as self-cleaning. The former type is best suited to wet climates and the latter, to dry climates. As for heat insulation, the type A coating is better because of the extra, ATO absorption, layer on the HGM. This largely prevents the transmission of infra-red light.

The hydrophobic coating was produced by a 'soft chemistry' method developed by the team with advice from the University's Department of Applied Biology and Chemical Technology. Readers interested in the detail should consult the relevant paper listed in Appendix 2.

The Work Undertaken

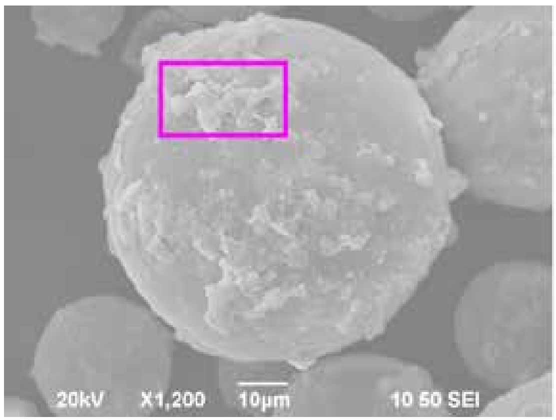
The research underlying the developments of the above coatings has been very considerable in extent. Full detail is available in Appendix 2.

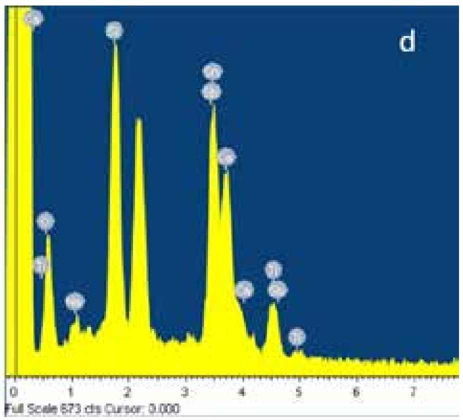


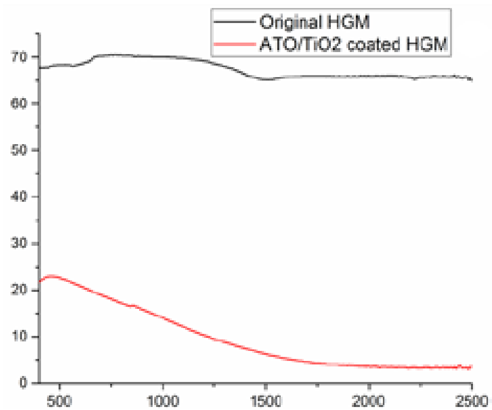
Particle distribution of those dispersion samples

Making the various coatings was itself a challenge. The ATO coating in Type A is an example. The final method started by mixing ATO with distilled water, a special dispersion agent and zirconium oxide balls to form a paste. This was 'ball-milled' for 12 hours at 3000 rpm and the dispersed sample extracted. Separately, HGM with distilled water added was stirred and the dispersed ATO sample was then mixed in with the HGM, one drop every 7 seconds. The ATO-coated HGM was then available. After the addition of more water, ethanol, and TBOT, the mixture spent 6 hours at 180°C in a hydrothermal reactor. The final product, in suspension in the liquid, was collected and dried at 80°C for 4 hours. The ATO-coated HGM was then placed on a glass substrate for 'characterization' of its properties.

Characterization included morphology studies using a scanning electron microscope (SEM), with thermal conductivity, light reflectivity, and transmittance measurements. The coating increased the thermal conductivity of unadulterated HGM by 8%. 19.6% of incidental light was reflected and overall transmittance was 86% less than that of pure HGM at only 7% of incidental light radiation.







5. Structural Assessment of a Large Vertical Axis Wind Turbine

Background

Horizontal axis wind turbines (HAWT) are dominating the commercial scene worldwide. Vertical axis wind turbines (VAWT), however, have apparent advantages, which have not been much researched on a large scale. (VAWTs are in common use only at small scales - on individual buildings for example). HAWT structures are not cheap, however. The significant wind force applied to the rotor must be transmitted to the foundation by a cantilevered support. Cantilevers are inherently structurally inefficient and expensive structures. Each rotor blade is itself also a cantilever needing a strong anchorage at the hub. A trade-off exists between the rotor diameter and the rotor weight, the latter increasing disproportionately quickly as blade length increases. Increased rotor inertia soaks up more wind energy, just in moving the rotor, and reduces responsiveness to wind speed changes. There is an engineering limit, therefore, to the amount of wind energy that can be garnered. A further cost-adding complexity is that the rotor must be free to swing around to face the wind.

A VAWT, in contrast, accepts wind from any direction. In addition, the wind forces on the vertical blades provide torque and rotor speed more directly than does a HAWT. The arms connecting the blades to the central spindle can be relatively light. They are not cantilevers but two-ended supported beams.

Overall, the VAWT has a simpler and cheaper structure, with less fatigue loading and less maintenance involved.

But of course there are disadvantages. Only wind from one side of the spindle pushes on the blades if the rotor is to turn. Blades on the spinning rotor which are returning in the opposite direction to the wind must be 'feathered' to minimize drag. Thus each blade must be automatically controlled in orientation ("blade pitch") about its vertical axis as the rotor spins, so as to maximize the turning moment each blade imparts to the rotor at any position around the circle and minimize its dragging moment when a positive contribution is not possible. This is a degree of control sophistication much easier to achieve today than in the 1980s when large VAWTs were briefly tried but abandoned. The arms, however, cannot be so controlled and wind arm forces both accentuate rotor spin and put a drag on rotor spin depending on the position of the arm around the spin circle. There is probably a net negative arm effect and a trade-off exists between this effect and the extra turning moment generated by the blades as arm lengths increase.

The Project and Its Objectives

The team had access to an existing straight bladed VAWT in Yang Jiang City (YJC), Guangdong Province, which was built by Hong Kong's Hopewell Holdings Limited. The VAWT's tower was 24 metres tall and the rotor 40 metres in diameter and 26 metres in height. There were 3 vertical blades to capture the wind, each of which was 200 centimetres wide.

The PI is exceptionally well experienced in structural instrumentation both for control purposes and structural health monitoring, i.e. in smart structures and applied that expertise to a further study of VAWTs. The main interests were *structural* and *control* in nature.

<u>Structural interests</u> included accurate micro-modelling of the fibre reinforced plastic blades looking for delamination tendencies and system scale structural modelling to assess fatigue loads and ultimate strengths. <u>Control interests</u> concerned the continuous control of blade pitch.

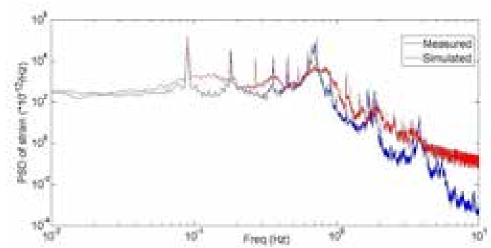
Project Outcomes

Project Achievements/ Findings

A method for simulating wind loads on a straight-bladed VAWT was developed based on strip analysis and CFD simulation and calibrated using the YJC turbine. Accurate modelling of wind is not easy given its variability over space and time, including its turbulent nature. The interaction between winds and structural loads in all structural components of the YJC were considered, and the spatial varying mean wind speeds and turbulences were included in the simulation. Predictions can now be made for proposed alternative dimensions. A key finding was that the influence of the arms did indeed significantly reduce turbine power output.

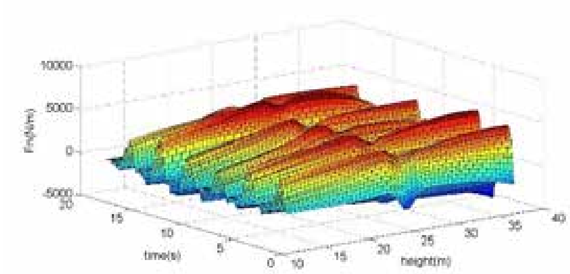
Much has been learnt about the stresses and strains within the vertical laminated composite blades and the effective laminar elastic constants and how to model blade behaviour. Bending tests were performed on a fibre reinforced plastic (FRP) blade and micromechanics models were developed using laminated shell elements. In addition, a framework for the fatigue and ultimate strength analyses of blades and other structural components was developed, embodying an FE model of the VAWT enabling the structural analysis of all components. In both normal operation and extreme wind conditions, the responses of blades and other components can be simulated and the critical fatigue failure locations and ultimate strength failure locations of the blade, shaft, arms and tower can be identified.

Field data measured on the Hopewell straight-bladed VAWT were used to validate the proposed framework. Assuming the same operational weather conditions, the responses of the VAWT FE model were simulated and found to match well with the measured responses, thereby validating the model.



Finally, the concept of the ***'smart' VAWT*** was presented. A smart structure ***synthesizes control, monitoring and power supply***. Blade pitch control used a sinusoidal pitch angle control algorithm. The structural health monitoring (SHM) system, self-powered, consisted of many sensors located throughout the structure (e.g. strain sensors). Sensor readings can be automatically checked at intervals and unexpected readings fed back for warning purposes.

Blade test (Courtesy of Hopewell Holdings Limited)



Simulated wind load

The straight-bladed vertical axis wind turbine (Courtesy of Hopewell Holdings Limited)

6. Protecting Sensitive Facilities Against Ground Borne Construction Vibrations

The Achievement

This project provided new data inside a healthcare building, on the vibrations caused by adjacent construction site piling. Because of the sensitivity of many types of medical instrumentation, site piling had previously been forbidden alongside healthcare building sites, for many hours during the day. In the case of mini-piles, however, the team's vibration measurements proved that piling hours could be safely extended, resulting in a HK$ 1.98 million saving over a 2.5 months long period. Never before produced anywhere, the team also developed a hardware/software system whereby the vibrations from an adjacent construction site can be continuously monitored at chosen locations, within a healthcare centre in this specific case. The system emits warnings if vibration levels reach pre-set values.

Data of practical use has also been produced. The effect inside the building, for example, of the distance between the piling operation and the edge of the building has been determined.

A guideline has been produced that was formally adopted by the Hospital Authority for assessing construction induced vibration impact on medical equipment.

The Motivation Behind the Research

Increasingly, equipment exists in many types of facilities, including medical facilities, which can be damaged by excessive vibration. The usual standards limiting the vibrations transmitted by construction site plant, are about 10 times less stringent than is nowadays required for some modern instrumentation. Much data is already available on ground borne vibrations induced by construction activities, but none for piling impact on vibration-sensitive medical equipment. The team has provided this data for mini-piling and showed it to be only about one quarter the severity of vibratory sheet piling.

An additional motivation was the need for a system which continuously monitored vibrations in the vicinity of sensitive instruments and emitted warnings when they came close to a maximum threshold.

The Case Study

Field work was essential to this study and a 3-storey concrete health care building was chosen standing on a raft foundation. The floor area was 1500m^2 with column spaces of typically 6.2 metres. Over 100 items of sensitive equipment were spread amongst several laboratories. The nearest mini-pile was only 2m from the external wall of the building and driven over 27m down to bedrock. Vibrations were measured, using accelerometers, at 5 external points ranging between 4.3m and 23m from that pile and 4 indoor locations close to sensitive instrumentation. Some outdoor measurements, in fact, were also made on other sites on vibratory sheet piling, bored piling and, again, mini-piling.

The first mini-pile driven and instrumented, with accelerometers outside and inside the building, was close to the building and allowed the effect to be gauged of outside distance on the strength of transmitted vibrations. As a result, it was estimated that any pile more than 10m away from the wall and drilling at a depth greater than 6m would not cause excessive vibration. Thus, two piling rigs could after all be operated in the mornings, without causing too much vibration, as long as they conformed to those distance and depth requirements. This caused a saving in downtime of almost 2 million dollars as stated above.

Project Outcomes

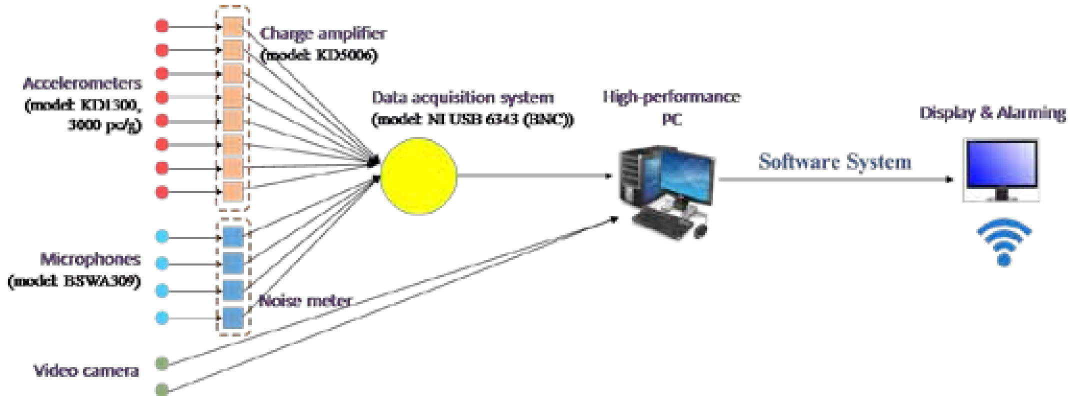
A Vibrations' Prediction Model

	Location 1	Location 2	Location 3	Location 4
Measured speed	184	156	173	55
Predicted	179	188	193	62

Vibration magnitudes, of course, relate to the distance between the piling and the building, depth of the piling, the nature of the ground, and the position in the building such as the floor level. To provide a prediction capability applicable to a hospital in general, a finite element model was built which represented the building structure and its vibration transmittance properties. The model also takes account of the location of the piling relative to the building, including the working depth. The experimental field work measurements were then checked against a simulation model of vibrations' transfer for the building in the case study. The table compares model predictions with measured values for the four indoor locations. The piling depth relating to these figures was 2.5 metres. The numbers are 1/3 octave band spectrum RMS velocities in micro-metres/second.

The Real Time Monitoring and Alarm System

The real time monitoring and alarm system has been implemented on the construction site expanding an existing healthcare centre. There are 15 accelerometers for monitoring vibrations and 1 microphone for monitoring excessive noise. The readings are all fed into a computer, which is linked to an output display unit capable of also emitting an alarm. The computer calculates all the necessary noise and vibration levels, compares them with pre-set allowable values and sets off the alarm if any get too high. This system is easily established at any future location where construction activity is likely to be a nuisance.



Mini-piling work

The cost saving due to the construction schedule adjustment			
Item	**Cost/per month (HKD)**	**Saving Months**	**Total cost (HKD)**
2 Piling Rigs, 2 Air Compressors, 1 Mobile Crane	300,000	2.5	750,000
3 Plant Operators, 4 Piling Workers, 2 Welders, 2 Steel Benders	420,000	2.5	1,050,000
10% Overhead			180,000
Total Cost Saving			1,980,000

Appendix 1 - The Project Team Members

Project 1 - An Innovative Stone Cladding Anchorage System for Buildings

Dr Jian-guo Dai	Principal Investigator
Dr Z Leng	Co-Investigator
Mr DY Sun	Research Assistant
Ms Y Zhang	Research Assistant

Project 2 - Indicators of Low Carbon Emissions Performance for Office Buildings

Professor Edwin Chan	Principal Investigator
Associate Professor PTI Lam	Co-Investigator
Assistant Professor EHK Yung	Co-Investigator
Mr P Lee	Research Associate
Mr MC Wang	PhD Student

Project 3 - Quantifying Transaction Costs for Green Buildings Delivery

Professor Edwin Chan	Principal Investigator
Associate Professor LHT Choy	Co-Investigator
Assistant Professor QK Chian	Co-Investigator
Ms K Fan	PhD Student

Project 4 - Novel Solar Heat Reflective Insulating Materials

Professor Hongxing Yang	Principal Investigator
Dr Lin Lu	Co-investigator
Dr Yuanhao Wang	Co-investigator
Mr Yan Hu	PhD Student

Project 5 - Structural Assessment of a Large Vertical Axis Wind Turbine

Professor You-Lin Xu	Principal Investigator
Mr Jinghua Lin	PhD Student
Mr Sheng Zhan	Research Fellow

Project 6 - Protecting Sensitive Facilities Against Ground Borne Construction Vibrations

Dr Songye Zhu	Principal Investigator
Dr Randolph CK Leung	Co-Investigator
Dr Xiang Shi	Research Associate
Mr Shiguang Wang	PhD Student

Appendix 2 - Publications Arising from the Projects to Date

The references below enable interested readers to follow up on any project in more detail.

At this stage, the list is in embryo form only, as most projects were finished relatively recently. Several papers are still undergoing review by journals so cannot yet be referenced.

Project 1 - An Innovative Stone Cladding Anchorage System for Buildings

1) Zhou Jialing, Dai Jianguo, Gao Hai et al., A new stone or metal façade-concrete system integrated with insulation, Patent:CN201520051269.2

Project 2 - Indicators of Low Carbon Emissions Performance for Office Buildings

1) Lee P., Wang MC., Chan EHW., *An analysis of problems with current indicators for evaluating carbon performance in the construction industry*, Creative Construction Conference 2016,CCC2016, 25-28 June. Procedia Engineering, Elsevier.

Project 3 - Quantifying Transaction Costs for Green Buildings Delivery

1) Fan K, Qian QK, Chan EHW. *Transaction Costs (TCs) in Building Regulations and Control for Green Buildings: Case Study of Hong Kong*. "Creating Built Environments of New Opportunities", 1, 818. The 20th CIB World Building Congress, 30th May to 3rd June, 2016, Tampere, Finland.

Project 4 - Novel Solar Heat Reflective Insulating Materials

1) Hu Y., Zhong H., Wang YH., Yang HX. *Development of an Antimony Doped Tin Oxide/TiO_2 Double layers coated HGM: A High reflectivity and Low transmittance Building thermal Conservation Material*. The 8th International Conference on Applied Energy, Energy Procedia, 00(2016) Elsevier.

2) Hu Y., Wang YH., An ZG., Zhang JJ., Yang HX. *"The super-hydrophobic IR-reflectivity TiO_2 coated hollow glass microspheres synthesized by soft-chemistry method."* Journal of Physics and Chemistry of Solids, 98 (2016) 43-49.

Project 5 - Structural Assessment of a Large Vertical Axis Wind Turbine

1) Jinghua LIN, *Structural Analysis of Large-Scale Straight-Bladed Vertical Axis Wind turbine with Health Monitoring and Control.*, PhD Thesis, (2016) The Hong Kong Polytechnic University

2) You-Lin XU, Jia HE. (2017). *Chapter 17: Synthesis of Energy Harvesting, Structural Control and Health Monitoring in Smart Civil Structures.* CRC Press

Project 6 - Protecting Sensitive Facilities Against Ground Borne Construction Vibrations

1) Zhu SY., Shi X., Leung RCK., Cheng L., Ng S., Zhang XH., Wang SG., "Impact of Construction-Induced Vibration on Vibration-Sensitive Medical Equipment: A Case Study," *Advances in Structural Engineering*. Vol.7 No.6, 2014, 15 pages.