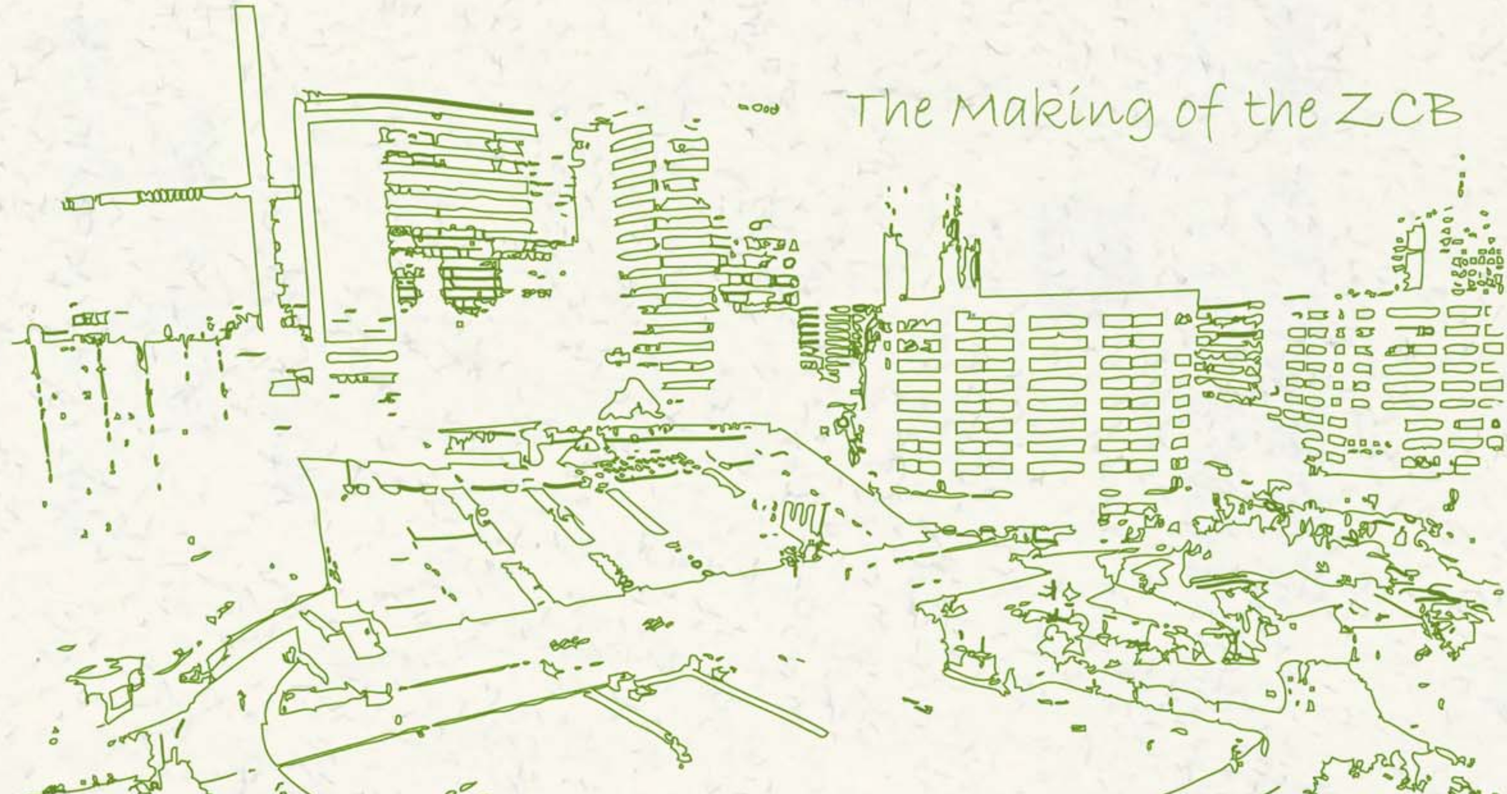
ZCB Zero Carbon Building Journal

Volume 1 | January 2014

The Making of the ZCB



CONSTRUCTION INDUSTRY COUNCIL
建造業議會

Zero Carbon Building JOURNAL

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Zero Carbon Building Journal
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Mr Paul MP Chan, MH, JP

Secretary for Development

The Government of the Hong Kong Special Administrative Region

I must first offer my warmest congratulations on the inaugural issue of the Zero Carbon Building Journal. We are honoured to have taken part in the development of the ZCB in collaboration with the Construction Industry Council. The ZCB, located at the heart of the densely built and vibrant commercial area of Kowloon Bay, is more than a signature green building in Kowloon East. It is truly a milestone of the green reform in Hong Kong.

Climate change is one of the biggest and most pressing global challenges ahead of us. We are living in a world with scarce resources, and competition for the gifts of nature is keen. Hong Kong must keep pace with the global trend of developing a low-carbon, sustainable and liveable community for our future generations.

In progressing towards a greener world, we are counting on the conservation efforts of the building sector, as it alone accounts for 60 percent of greenhouse gas emissions. Re-engineering may be our key.

By "re-engineering" I refer to a new philosophy or a rethinking process in regard to the construction cycle that enables wiser and more efficient deployment of resources, and prompts adaptation or even development of new technologies.

The ZCB is a vivid example. This project has brought together more than 80 different eco-building technologies, with some of the methods being adopted for the first time in Hong Kong. The ZCB's successful concerto of green building initiatives has been widely recognised, as we can see from the BEAM Plus Platinum rating and other awards it has collected.

It is fitting that the inaugural issue of the Zero Carbon Building Journal tells the story of this state-of-the-art project. It is appreciated that the ZCB is sharing with the world its experience and knowledge without reservation. In subsequent publications, the Zero Carbon Building Journal, I expect, will be an effective platform for sharing information on the latest low- and zero-carbon building technologies and the evaluation of such technologies for wider application.

I am glad to see that the ZCB has established itself, and that a global audience is learning more about its accomplishments. Hong Kong, Asia's world city, has every opportunity to develop itself into Asia's green world city through the concerted efforts of the ZCB, the Construction Industry Council, the Government, the construction industry and other green stakeholders. I am confident that, with the community's support, we can build a harmonious, prosperous and green city together.

Paul MP Chan
Secretary for Development
The Government of the Hong Kong Special Administrative Region

Mr Kam Sing Wong, JP

Secretary for the Environment
The Government of the Hong Kong Special Administrative Region

In Hong Kong, buildings are responsible for 60% of total GHG emissions. We are also aware of the encouraging fact that the building sector has the greatest economic potentials for mitigating GHG emissions using technologies and practices in the coming decades, as demonstrated in the assessment report of the Intergovernmental Panel on Climate Change established by the United Nations Environmental Programme and the World Meteorological Organisation. Raising the environmental performance of buildings gives us a promising future in our attempt to combat climate change and to achieve sustainability of our built environment.

The *Zero Carbon Building Journal*, with the aim to provide a broad range of information about the recent advances of low/zero carbon building technologies, will stimulate the adoption of innovative designs and measures, and encourage the deployment of new technologies that will contribute to the reduction of GHG emission. It will assist developers and building professionals in making the right choices that can strike an appropriate balance between our development needs on the one hand, and the need for protecting our environment on the other.

The inaugural issue of the *Zero Carbon Building Journal* marks an auspicious beginning for pioneer publication. It offers an impressive combination of articles on the design and construction of the first of its kind Zero Carbon Building project in Hong Kong. The articles captured by the Journal are authored by highly knowledgeable experts, and demonstrate impeccable scholarship.

The founding of this *Journal* is an exciting development in the promotion of green buildings in Hong Kong. I hope our partners in the building sector will make full use of this common platform to share their research and ideas, and promote our common goal of developing a low-carbon community and promoting sustainable development in Hong Kong.

KS Wong
Secretary for the Environment
The Government of the Hong Kong Special Administrative Region

Editorial

During the course of developing the ZCB – the first Zero Carbon Building in Hong Kong, the Task Force on Zero Carbon Building set up by the Construction Industry Council, had the view that it is equally important to evaluate the performance of the various green technologies and disseminate the information to the construction industry as it is to develop the showcase building itself. With over 80 different green technologies adopted throughout the ZCB, and a planned programme of progressive upgrading, the performance evaluation of the technologies will be an on-going process.

The main objective of this Journal is to disseminate research on the latest low/zero-carbon building technologies and practices from around the world as well as to disseminate the results of the performance evaluation of the technologies adopted at ZCB. Initially, the Journal will be published twice a year in January and July.

The ZCB project is a symbol of true collaborative team work. The Task Force played an overarching role throughout the project. Comprising top green building specialists, architects, engineers, quantity surveyors and other practitioners on a community service basis, the Task Force provided strategic input for every key aspect of the project development, from positioning the plant room at the basement courtyard for ease of public viewing to the inclusion of Hong Kong's first native urban woodland in the development to promote biodiversity.

The members of the Task Force were: Mr YU Waiwai (chairman), Mr CHAN Siu-hung, Mr Peter CHENG, Mr CHEUNG Hau-wai, Mr Stephen LAI Yuk Fai, Mr LAM Wo-hei, Mr Ricky LAU Chun Kit, Miss Salenda LAU, Mr Edmund LEUNG Kwong-ho, Mr Michael LI Kiu Yin, Mr Kelvin LO, Ms Catherine NG, Professor Edward NG Yan-yung, Mr Christopher TO, Mr Christopher TUNG, Professor WANG Shengwei, Mr Benny WONG Yiu Kam, Miss Charmaine WONG Hoi Wan and Mr Conrad WONG.

Acknowledgement should also be given to the following members of Task Groups who made valuable contributions on specific aspects of the project development: Mr HO Wai Yip, Mr Sean LEUNG, Mr Leo LI, Mr SHEK Lap Chi, Mr Tony SIN, Mr WONG Kam Sing and Mr Donald YEE.

The professional communities in Hong Kong showed their great support for this initiative by selflessly sharing their professional views and thoughts at a number of dedicated forums and workshops.

From inception to completion in June 2012, the whole project took only eighteen months. It would be impossible to achieve this without the tireless effort and dedication of the consultants and contractors. Therefore it is very fitting to dedicate the first issue of this Journal to the ZCB project experience. There is much to be shared from this project with the readers.

Dr Guiyi Li
Chief Editor

DELIVERING ZERO CARBON BUILDINGS: THE STATUS QUO AND WAY FORWARD

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Summary

Zero carbon building (ZCB) has emerged as an innovative model of sustainable building. This paper examines the current status and the way forward for delivering ZCBs. An analysis is carried out in relation to ZCB principles, policies, practices and priorities; drawing on debate in both research and practice. The results show that although ZCB is gathering momentum worldwide, the understanding of the model is fragmented and ZCB policies are unclear. There has been a proliferation of attempts to achieve zero carbon, but ZCB practices are inconsistent and any application to high-rise buildings remains unexplored. Priorities in achieving zero carbon and sustainability are often in conflict with each other. In order to move forward, this paper recommends that ZCB principles should be explicitly defined within appropriate political, social, climatic and geographic boundaries. Key to these principles is the unit of balance, the period of balance, and the energy scope and grid connection. Also, the formulation, implementation and review of ZCB policies should be grounded in systems approaches. Technical solutions may vary but can be grouped around passive design and energy efficiency, on- and off-site renewable energy technologies, and carbon offsetting measures. Transforming ZCB prototypes into mainstream practice is imperative and requires zero carbon parameters be integrated into project delivery systems.

Keywords

zero carbon building, carbon emissions, principle, policy, practice, priority

Introduction

A worldwide transition towards low carbon and sustainability is critical to ameliorating the serious global risk of climate change. Buildings worldwide account for as much as 45% of energy consumption and carbon emissions (Butler, 2008), standing out as the biggest contributor to anthropogenic climate change. Zero Carbon Building (ZCB) has emerged as an innovative model of sustainable development of the built environment and is gaining momentum in the world (Ramos and Burrows, 2011). However, the delivery of ZCBs faces significant challenges.

First, there exists no commonly accepted definition of ZCB, though whether or not adopting a common definition is practical remains a point of debate. Previous research (Marszal et al., 2011; Sartori et al., 2012) has suggested an existing fragmented understanding of ZCB worldwide. Critical debate also exists regarding the scope of 'zero carbon' in relation to a building's lifecycle: for example, whether or not the focus is on regulated, user-related and/or embodied carbon/energy (Pan, 2013). The lack of a consistent understanding of ZCB principles inhibits the development of clear ZCB design strategies.

Secondly, very few countries and regions have developed their ZCB policies. ZCB is often regarded, explicitly or implicitly, as part of a nation's climate change policy or building energy codes and regulations (Ramos and Burrows, 2011; Pan and Garmston, 2012). Also, ZCB policies have encountered serious debate on two issues. One is the scope of energy that carbon emissions are associated with, with absolute zero carbon (covering all regulated and unregulated energy use) at one end of the scale, and regulated energy only at the other. The other issue is that, though it has been widely acknowledged that achieving zero carbon requires combined measures of energy efficiency, on- and off-site renewables, and carbon offsetting; the specifics and the share of carbon emission reductions in achieving the zero carbon target are still under scrutiny (McLeod et al., 2012; Zero Carbon Hub, 2011).

Thirdly, the practices of ZCB to date are inconsistent and insufficient. This is partly attributed to the lack of understanding of ZCB principles and partly to the vagueness and uncertainty of ZCB policies. Little knowledge is available regarding on the relationships and interactions between the supply, demand, regulation and institutional sides of ZCBs, and attempts to explore the split among the energy production and supply sector, the building industry, and end-users in their contributions to carbon reductions have been few (Pan 2013). Renewable energy technologies are commonly used for achieving ZCBs, but they are often undertaken as quick-win strategies at the expense of underexplored energy efficiency measures and, consequently, debateable long-term sustainability. Furthermore, there exists no reported ZCB in the context of dense high-rise buildings at the time of this paper, which suggests an urgent need for research and development given our rapid global urbanisation and regeneration.

Finally, few studies have examined the priorities of ZCB from a systems perspective, that is, with limited knowledge of the relationship between the carbon parameter and other environmental factors and social and economic concerns. ZCBs with an overspecialisation on the carbon parameter per se may not result in economic or social sustainability.

This paper examines the current status and the way forward for delivering ZCBs. The examination is carried out using the '4P' framework to cover the principles, policies, priorities and practices of ZCB. It draws on knowledge and practices worldwide but focuses on the dense urban context.

Principles of ZCB

The key principles of the concept of ZCB include: unit of balance; period of balance; energy scope; and connection with grid.

Unit of Balance

The literature on the concept of ZCB indicates six types of unit of balance, namely: final/delivered energy, primary energy, carbon dioxide (CO_2) emissions, exergy, energy cost and emergy. Marszal (2012) argued that selecting a specific unit of balance is influenced by the project goals and cost, the intention of the investor, the concern over climate change, the intention of evaluating the building's complete impact on the environment, and the requirements of the building code.

Among the six units of balance, energy is mostly acknowledged. Marszal (2012) suggested that primary energy is preferred to final energy, as it takes the quality of different energy carriers into account. Since buildings are evaluated and certificated based on energy performance, using the unit of balance CO_2 emissions for calculations is not favoured, despite its merit of sharpening the arguments for tackling the urgency of climate change.

Kilkis (2012) added exergy as another unit of balance, indicating that in balancing the zero both quantity and quality (exergy) of energy should be taken into consideration. Besides exergy, an emergy analysis can also can be applied to a building to account for the main energy and material inflows to the processes of building manufacturing, maintenance and use (Pulselli et al., 2007). Emergy analysis is concerned with quantifying the relationships between human-made systems and the biosphere. When applied to a building, it quantifies all the natural resources used for building manufacturing, maintenance and use.

Period of Balance

The period of balance is another critical principle of the ZCB concept. Previous research (Marszal, 2012) has proposed five typical types of period of balance: month, season, year, operating lifetime, and full lifecycle. An annual balance is the most favoured in both research and practice, primarily because an annual balance complies with most building energy regulations and standards. More research has started to adopt the lifecycle assessment approach by evaluating embodied energy, however, the evaluation of embodied energy introduces another point of debate due to the diversity of boundaries and insufficient input data.

Energy Scope

The energy scope of ZCBs may vary significantly. Total energy use in the lifetime of a building may include:

- Building related energy, such as heating, cooling, ventilation, domestic hot water, and lighting;
- User related energy, such as cooking, and appliances;
- Embodied energy, found in building materials and installations and for building construction, maintenance and renovation, and demolition.

International Standard EN 15603:2008 states that in the 'energy performance of buildings – overall energy use and definition of energy rating' the energy rating calculation should obligatorily include only the energy use that does not 'depend on the occupant behaviour, actual weather conditions and other actual (environment and indoor) conditions'. In particular, it includes heating, cooling and dehumidification, ventilation and humidification, hot water and lighting (for non-residential buildings).

Hernandez and Kenny (2010) adopted primary energy as the indicator for annual energy use in operation and for embodied energy in a lifecycle zero energy–building framework. They explained that primary energy allows differentiation between electricity and fossil-fuel use and includes an indication of the efficiency of delivering heating and hot water. Another reason is that where CO_2 is considered appropriate, conversion factors from primary energy to CO_2 can easily be integrated into the proposed methodology and definition available for most regions or countries. Hernandez and Kenny (2010) have thus asserted that the full lifecycle of a building could be a more appropriate period for the energy balance.

Connection with Grid

Whether or not a building is connected to the grid is also a critical principle of the ZCB concept. The most common approach is to use the electricity grid both as a source and a sink of electricity without on-site electric storage systems. The term 'net' is used in grid-connected buildings to define the energy balance between energy use and energy sold (Hernandez and Kenny, 2010).

When a building is connected to grid, there are two possible balances between: 1) the energy use and the renewable energy generation, and 2) the energy delivered to the building and the energy feed into the grid. Because the results of adopting the two balances are the same in most cases, the main difference is the period of application (Marszal et al., 2011).

By contrast, autonomous buildings (called zero stand-alone buildings) do not require connection to the grid or only require a grid connection as a backup. Autonomous buildings can supply themselves with energy, as they have the capacity to store energy for night time or winter use (Marszal et al., 2011). Vale and Vale (2002) argued that connecting a domestic renewable system to the electricity grid and achieving a 'net-zero energy' home can have better lifecycle performance than an autonomous house because the use of electric storage systems is avoided and some flexibility in the use of appliances is gained. However, Torcellini et al. (2006) argued that achieving a zero energy building (ZEB) without the grid would be very difficult, as the current generation of storage technologies is limited. Nevertheless, they also acknowledged that in high market penetration scenarios, the grid might not always need the excess energy from the ZEB; therefore, on-site energy storage would become necessary.

The four principles, albeit being examined individually for clarity, are interconnected. They underpin the complexity and complications of the ZCB concept.

Policies for ZCB

Several pioneering countries and regions have formulated their ZCB policies in line with their climate change and building energy policies (Table 1). It is worth noting that the underlying meaning of 'zero carbon' varies.

Table 1 ZCB policy initiatives

Initiative	Description
United Kingdom (UK) Building a Greener Future: Policy Statement (DCLG, 2007)	Achieve zero carbon new homes by 2016, with 25% carbon reduction from building regulations by 2010, and 44% by 2013.
United States (US): Energy Independence and Security Act 2007 (EISA, 2007)	As of 2025, all new commercial buildings must be zero net energy; As of 2050, all commercial buildings must be zero net energy including retrofits of pre-2025 buildings.
US:Presidential Executive order (EO)13514 (Federal Office, 2009)	As of 2020, all planning for new Federal buildings requires design specifications that achieve zero net energy use; As of 2015, at least 15% of any Federal agency's existing buildings and building leases above 500 m² must conform to zero net energy.
European Union (EU): European Directive 2010/31/(recast) (EC, 2010)	As of 31 December 2020, all new buildings are nearly zero energy buildings; After 31 December 2018, new buildings occupied and owned by public authorities are nearly zero energy buildings
US: California BBEES (California Energy Commission, 2011)	As of 2020, all new residential construction in California to be zero net energy As of 2030, all new commercial construction in California to be zero net energy

The UK was the first country to set a timetable for delivering ZCBs: to achieve zero carbon for domestic buildings from 2016 and for non-domestic buildings from 2019 (CLG, 2008). However, such policies and their underlying definitions have encountered serious debate. The debate focuses mainly on the scope of energy with which carbon emissions are associated, from the originally proposed 'genuine' or 'complete' zero carbon (including both regulated energy, i.e. for space heating, cooling, ventilation, lighting and hot water; and unregulated energy, i.e. for cooking, washing and electronic entertainment appliances, DCLG, 2006:7) to 'regulated' energy only (HM Treasury, 2011:117).

Underlying these ZCB policies are ZCB strategies. The UK strategy consists of three tiers: 1) good fabric energy efficiency; 2) inclusion of on-site low carbon heat and power technologies; and 3) use of allowable solutions to compensate carbon emission reductions that are difficult to achieve on site (Zero Carbon Hub, 2011). The building is to have net zero carbon emissions over the course of a year. In order to meet the UK zero carbon homes standard, a home should be built with high levels of energy efficiency; achieve at least a minimum level of carbon reductions through the combination of energy efficiency, onsite energy supply and/or directly connected low carbon or renewable heat; and choose from a range of (mainly off-site) solutions for tackling the remaining emissions.

In the US, according to the Presidential Executive Order 13514, 'zero-net-energy building means a building that is designed, constructed, and operated to require a greatly reduced quantity of energy to operate, meet the balance of energy needs from sources of energy that do not produce greenhouse gases, and therefore result in no net emissions of greenhouse gases and be economically viable'. The Energy Independence and Security Act (2007) uses the same definition but focuses on commercial buildings.

In the Big Bold Energy Efficiency Strategies (BBEES) initiated by the California Energy Commission, zero net energy is a net energy consumption of zero over a typical year. To cope with fluctuations in demand, ZEBs are typically envisioned as connected to the grid, exporting electricity to the grid when there is a surplus, and drawing electricity when not enough electricity is being produced. This definition has however attracted intensive debate since its introduction in 2008. California Energy Commission (2013:28) recommended a new definition that "a ZNE [zero net energy] Code Building is one where the societal value of the amount of energy provided by on-site renewable energy sources is equal to the value of the energy consumed annually by the building at the level of a single "project" seeking development entitlements and building code permits, measured using the California Energy Commission's Time Dependent Valuation metric."

In the EU context, as of 31 December 2020, new buildings will have to consume 'nearly zero' energy and the energy they do consume is largely meant to come from renewable sources. The German government aspires to achieve new homes that are independent of fossil fuels by 2020. In that case, the policy of zero energy or positive energy buildings differs from current standard requirements as the German government's policy addresses both the needs of the building, and the balance of needs with on-site energy generation (Koch et al., 2012).

The review above suggests that there are two critical aspects to formulating and implementing ZCB policies: one is to explicitly set the boundary of energy scope with which carbon emissions are accounted, and the other is develop a multi-tier strategy for achieving the zero carbon target which covers energy efficiency, on- and off-site renewables, and carbon offsetting, and specifies their relative shares.

Practices of ZCB

Numerous ZCBs have emerged but often under a variety of names: 'net zero' energy building, 'nearly zero' energy building, and 'zero emissions' building, for instance. Musall

(2013) mapped almost 300 'net zero-energy and energy plus buildings' worldwide (Figure 1). However, the majority of the buildings are located in western countries. Also, small buildings outnumber blocks of flats, and there are virtually no high-rise ZCBs. Overall, very few ZCBs exist in dense areas in the subtropical region.

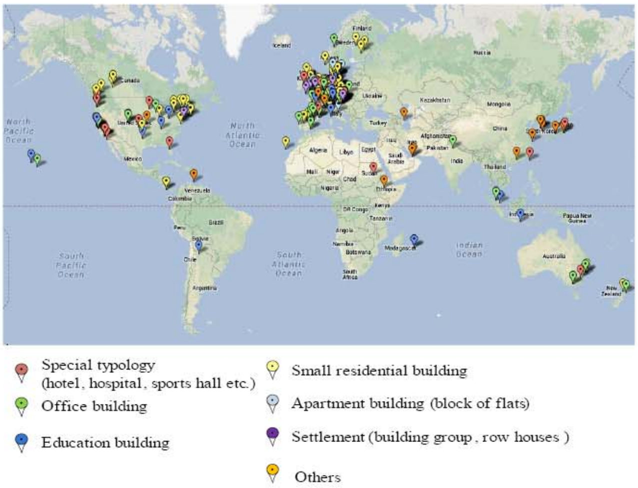

Figure 1 Net Zero Energy Buildings World Map (updated until Jun 2013) *(Courtesy of Eike Musall)*

ZCB practices are examined below in more detail in four aspects: technical, commercial, supply chain and market preference. Several ZCBs are referred to for illustration. These are located in five geographic areas: the US, Europe, Singapore, Australia and Hong Kong (Table 2).

Technical Feasibility

Evidence exists that ZCB is technically achievable with dedication to rational design strategy incorporating passive design and energy efficiency coupled with the use of on- and/or off-site renewable technologies. For example, in achieving net zero energy, the Melink Headquarters building (Figure 2) located in Cincinnati, Ohio, adopts a range of green features including on-site solar photovoltaics (PV) and wind turbine systems to general electricity, and geothermal, solar thermal and biomass systems to offset building energy use.

Figure 2 Melink Headquarters Building, Cincinnati, Ohio *(Courtesy of Melink Corporation)*

However, it is worth noting that most ZCBs to date are low-rise. It is largely unknown whether or not high-rise ZCBs in high-density areas are technically feasible.

Table 2 Selected Zero Carbon Buildings for illustration

Project	Performance	Characteristics	Technical solutions
Melink, Cincinnati, Ohio (Minor and Hallinan, 2013)	Net zero energy building LEED EB Platinum	· Renovation; · Both manufacturing and office functions; · 2,902 m²	· Energy efficient building design · On-site PV and wind turbine · Geothermal · Solar thermal and biomass systems to offset building energy use · Optimised building control
BOLIG+, Denmark (Marszal and Heiselberg, 2011)	The first demonstration project of a multi-storey residential net ZEB in Denmark	· Residential building; one part of 6 storeys and a second part of 10 storeys; · 7000 m²; · Assembled from 114 modules with an average area of 61.4 m²	· Reduce the energy use to a minimum, apply renewable technologies to offset the remaining energy consumption · PV installation combined with PV/T and a solar heat pump
Pixel Building, Melbourne, Australia (Zuo et al., 2013)	The first carbon neutral office building in Australia	· Small scale commercial building; · Investment of $6 million; · Four floors 1,000 m²	· Material selection is critical, like using pixelcrete, second-hand access flooring, second-hand carpet tiles, recycled timber, low-VOC paints, second-hand photovoltaic cells, and double glazing
CIC Zero Carbon Building, Hong Kong (CIC, 2012)	The first zero carbon building in Hong Kong; BEAM Plus Platinum	· 3 stories including basement; · A footprint of approximately 1,400 m² invested by CIC and the HKSAR government	· Passive design · Green active systems · Biofuel tri-generation system · PV panels · Low embodied carbon materials
Zero Energy Building @ BCA Academy, Singapore (BCA, 2009)	The first zero energy building in Singapore	· Renovation Government office and academic facilities · Investment of S$11 million by BCA, Singapore 4,500 m²	· Passive design · Active solutions: energy efficient building systems and equipment · Active control: management and optimisation and user discipline

Frechette and Gilchrist (2008) reported the Pearl River Tower (a 71 storey, 310 m office tower, with associated conference facilities and a total gross area of approximately 2.2 million square feet) was initially designed to be a net zero building. However, due to economic considerations and regulatory challenges, it failed to meet a net zero energy standard although it is still the most energy efficient super tall tower building.

Commercial Viability

Commercial viability is a serious concern in the delivery of ZCBs. Osmani and O'Reilly's (2009) survey found that additional costs associated with building ZCBs was a major financial impediment. Long payback periods of micro-generation technologies, such as PV, are of particular concern to their adopters (Davies and Osmani, 2011). Fleming (2009) analysed government and local utility rebates, incentives, and the feed-in tariff programme that were included to help offset the increased initial investment based on a 30-year period. The study revealed that creating an affordable ZCB in a hot humid climate like Gainesville, Florida, is both technically and commercially feasible with dedication to schematic design, a whole-building systems approach, and implementation of cost-effective components. However, this may not be feasible in other contexts such as Hong Kong, where, as Fong and Lee (2012) pointed out, there is no subsidy or incentive scheme for the installation of the solar panels and other renewable energy facilities.

To increase the commercial viability of ZCBs, Marszal and Heiselberg (2011) suggested that it is crucial to first reduce the energy use to a minimum and afterwards apply renewable technologies to offset the remaining energy consumption. In the case of multi-storey ZCBs, Marszal and Heiselberg (2011) also recommended that prefabricated modular building construction could have great potential for reducing the cost of construction with higher thermal properties. Nevertheless, there is a lack of research on the commercial viability of ZCBs.

Supply Chain Competency

Supply chain competency is important to deliver ZCBs. In the case of Pixel Building in Melbourne (Figure 3; Table 2), Zuo et al. (2013) found that the reuse and recycling of materials helped to achieve the carbon neutrality goal. A implication is that material suppliers should increase their competency in supplying greener products and materials. In addition, Zuo et al. (2013) noticed that all project participants in the Pixel Building were expected to integrate the supply chain early in the development process in order to achieve the goal of carbon neutrality.

Figure 3 Pixel Building, Melbourne *(Courtesy of CBRE)*

Market Preference

Due to the real or perceived higher capital costs of building towards zero carbon, compared to conventional construction, ZCB practices do face market barriers. As a result, government regulation and incentives are important to help unlock market potential. The first ZCB in Hong Kong and the first ZEB in Singapore (Figure 4; Table 2) were both publicly funded, with the goals of showcasing state-of-the-art eco-building design and technologies, and increasing public awareness of low carbon living. Both Hong Kong and Singapore set good examples of demonstrating the significant role of government in leading carbon emission reductions in the building sector.

Figure 4 The first Zero Energy Buildng in Singapore *(Courtesy of Building & Construction Authority)*

Priorities of ZCB

Reducing building carbon emissions has attracted much government policy attention in targeting anthropogenic climate change, but the carbon and energy parameter dominates building energy research, while other factors are often overlooked or sacrificed. As a result, a highly scored 'sustainable' building might not achieve zero carbon, and a ZCB may not score high at all in its overall environmental sustainability (Pan, 2013). ISO (2008:7) specifies that the 'sustainable development of buildings and other construction works brings about the required performance and functionality with minimum adverse environmental impact, while encouraging improvements in economic and social (and cultural) aspects at local, regional and global levels'. To achieve a zero carbon target should not be at the expense of the other parameters of sustainable buildings.

The management of ZCBs in any single aspect – technical, socio-cultural, political, environmental or commercial – may not guarantee the success of the whole business. For instance, Zoulias and Lymberopoulos (2007) argue that the replacement of fossil fuel based gensets with hydrogen technologies is technically feasible, but still not economically viable unless significant reductions in the cost of hydrogen technologies are made in the future. Similarly, Chang et al. (2013) suggest PV technology is economically feasible but its market value may be significantly distorted by the policy factors. The overspecialisation of building research and practice in carbon/energy represents a problematic oversimplification of sustainable buildings. Therefore, there is a need for more trade-offs (ideally win-wins) in managing the priorities of ZCB.

The management of ZCB priorities stems from the management of the delivery processes of building projects. However, such management has been criticised for their shortfalls in meeting the requirements for delivering green buildings (Lapinski et al., 2005; Chong et al., 2009). As buildings become more complex, the need for the integration of different kinds of expertise also increases (Berker and Bharathi, 2012). Newsham et al. (2009) identified four gaps in achieving planned performance: 1) the occupancy hours differ from those in the initial design assumptions; 2) the final as-built building differs from the initial design; 3) experimental technologies do not perform as predicted; 4) plug loads are different than assumed; and 5) a knowledge transfer gap exists between the design team and end users. This may be because team members face a steep learning curve in delivering green buildings, (Chong et al., 2009) or exhibit strong resistance to new technologies.

ZCB - The Way Forward

In line with the sweeping global agenda of reducing carbon emissions, ZCB will endure as an advanced model of sustainable building. Using the '4P' framework a number of strategies are developed for ZCB in the future.

For ZCB principles, the unit of balance, period of balance, energy scope and any connection with the grid should be explicitly defined. There is no universally agreed definition of ZCB or of its principles; though whether or not a universally agreed definition and principles of ZCB would be needed is a point of debate. However, it is certain that any definitions and principles should be set within the political, social, climatic and geographic boundaries of concern.

In relation to ZCB policies, their formulation, implementation and review should be grounded in systems theory within their boundaries. Despite the boundary specifics, it is still useful to promote cross-country critical learning to enable the formulation, or to inform the review of ZCB policies. Practical ZCB policies should clearly specify the shares of carbon emission reductions in achieving the zero-carbon target by the energy production and supply sector, the building industry, and end-users.

As for ZCB practices, there is a need for a systems integration of design strategies, including passive design and energy efficiency, on- and off-site renewable energy technologies and carbon offsetting measures. The use of site-based technologies should consider site specifics and geographic constraints. Emerging technologies should be explored for delivering buildings towards zero carbon, particularly in dense high-rise contexts, for which significant opportunities for research and innovation lie ahead. It is also (if not more) important to promote low carbon behaviours and lifestyle to help reduce energy demand. As there is very little knowledge of delivering high-rise ZCBs, examining the feasibility of the transition from low-rise to high-rise ZCBs is critical. Pan and Ning (2013) suggested that such a feasibility study should adopt a systems approach grounded in requisite holism theories (Mulej, 2007). Pan and Ning's (2013) approach addresses five aspects of feasibility, namely: technical feasibility, commercial viability, supply chain competency, market preference, and statutory and regulatory acceptance. Such a systems examination would then yield useful learning for enabling an accelerated take-up of ZCB practices and for informing the formulation and review of ZCB policies.

In ZCB priorities, it is important to align the zero carbon target with project outcomes. To integrate the zero carbon parameter into current procurement systems is an indispensable step in transforming the ZCB prototype into mainstream practice. To facilitate this transformation, more scientific evidence is needed on the quantified measurement of carbon emissions and its relationships with other project metrics, such as cost and productivity. It is speculated that the integration of the zero carbon parameter into project delivery will lead to win-wins in the long-term. However, such gains would not be sustainable without clarified principles, supportive policies and consistent practices of ZCB.

Implications for Hong Kong

In Hong Kong, buildings consume 90% of electricity and contribute to 60% of carbon emissions (EPD and EMSD, 2010). These are much higher than worldwide averages (Butler, 2008; Pan and Garmston, 2012). Subsequently, buildings in Hong Kong impose a significant challenge to carbon emission reductions, but they also provide a great opportunity to improve reductions. The Hong Kong Green Building Council (HKGBC, 2012) has proposed the 'HK3030' vision based on demand-side management to reduce 30% of the absolute electricity consumption in buildings by 2030 compared to 2005 levels. In his 2013 Policy Address, the Chief Executive of the Hong Kong SAR government committed to promoting green building, reiterating the government's policy support to building carbon reductions. These contextual factors combined suggest an unprecedented opportunity for ZCB to help drive the transition of Hong Kong's built environment towards a low carbon and sustainable one.

The Construction Industry Council (CIC 2012) completed the first ZCB in Hong Kong (Figure 5; Table 2) in 2012. It is a signature project which showcases state-of-the-art green design and technologies to the construction industry and to raise community awareness of sustainable living.

Figure 5 The first ZCB in Hong Kong *(Courtesy of Construction Industry Council)*

However, this ZCB is a prototype. Transferring the knowledge and learning process of this three-storey ZCB to the mainstream practice of constructing a typical 40 storey height building in Hong Kong introduces tremendous challenges technically, commercially and socio-culturally.

A mission to deliver high-rise ZCBs in Hong Kong in a systems manner is therefore critical. The '4P' analytical framework and the strategies for the way forward provided in this paper should support this effort. Learning from ZCB policies and practices worldwide, particularly where similar political, social, climatic and/or geographic conditions exist, should inform such endeavours.

The 2013 Policy Address envisions "Hong Kong turning into a healthy, low-carbon and resource-saving metropolis that is in harmony with nature" (Chief Executive, 2013:47). Knowledge of delivering high-rise ZCBs should help position Hong Kong as a leader in urban sustainability in the Asia Pacific Region and beyond.

Conclusion

This paper has examined the status quo in the delivery of ZCBs. Drawing on the '4P' framework of principles, policies, practices and priorities, four observations are made: 1) there is a fragmented understanding of ZCB principles; 2) unclear and uncertain ZCB policies are associated with these principles; 3) ZCB practices to date are inconsistent and insufficient; 4) priorities in the delivery of buildings towards zero carbon and sustainability are inherently in conflict. The limited body of knowledge of ZCBs is further constrained within the context of dense urban development. The design and delivery of zero carbon high-rise buildings in urban environments is largely unknown and unexplored.

Nevertheless, as an innovative model of sustainable development, ZCB continues to gather momentum. In order to tackle the challenges inhibiting an accelerated uptake of the ZCB model, further research, development and innovation is urgently needed. Such efforts should explore the potential of emerging technologies and simultaneously empower society's capacity for delivering ZCBs. There is no other solution to delivering ZCBs but building and sustaining a joint force capable of integrating the supply, demand, regulation, and institutional sides of buildings.

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Site Selection of the ZCB

ZCB is situated on a 14,700 m² site at Sheung Yuet Road, Kowloon Bay, Hong Kong. The building is set within a dense urban area on a brownfield site that was used as an open training ground for the Construction Industry Council.

The challenges for the ZCB were:

- Building in a hot and humid climate unique to Hong Kong;
- Developing a low-rise building in close proximity to numerous high-rise buildings;
- The site being surrounded by streets with heavy traffic;
- A drainage reserve running across the site.

Careful attention was therefore paid to the placement and layout of the three-storey 1,400 m² Zero Carbon Building and its surrounding open space. Investigations into the microclimate of the urban district helped to determine the siting, form and orientation of the building.

A brownfield site that was a CIC training ground

The ZCB under construction

Ariel view of ZCB 2013

SUB-TROPICAL LOW / ZERO-CARBON ARCHITECTURE FOR ECO-EFFICIENCY

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Summary

The paper will use the Construction Industry Council (CIC)'s Zero-Carbon Building (the ZCB), the first zero-carbon building in Hong Kong, as a reference to discuss the key design issues and integrated project delivery of sub-tropical low/zero-carbon architecture for eco-efficiency in a high-density/high-rise context.

ZCB's design journey involved a critical examination of the constraints and opportunities of the Place, Process, Programme and People to deliver the targeted Performance – a quality built environment with reduced environmental loadings. A clearly defined vision, targets and strategies on place-making, a collaborative design process striving for eco-efficiency from a life-cycle perspective, a design for flexibility which promotes synergy between functional programmes, and, last but not least, the delivery of an inspirational and effective built environment that supports a sustainable way of living were the critical factors to success.

Specific challenges of the high-density/high-rise, sub-tropical context of Hong Kong to low/zero-carbon developments were addressed to formulate effective design strategies, including: a sustainable neighbourhood for liveability, connectivity and eco-landscape; building design for hybrid ventilation, daylight, and views, and a high-performance building envelope, among other factors. The key question asked was: How can we use less and do more? The answer demands a critical examination of design norms, the identification of inefficiencies and misplaced resources, and architectural design responses to the urban climate and in the context of the neighbourhood.

Keywords

integrated project delivery, low/zero-carbon design hierarchy, eco-efficiency, sub-tropical, sustainable building design and site planning

Introduction

The world is under increasing pressure from climate change. The latest Intergovernmental Panel on Climate Change Report (IPCC, 2013) assessed and confirmed the likelihood of further global warming and human contribution to the observed climate changes. To combat climate change, the Hong Kong Government has proposed a voluntary target to reduce its citywide carbon intensity of 50% to 60% by 2020 compared with its 2005 level (HKEPD, 2012). Hong Kong's buildings account for 90% of the city's electrical consumption. Buildings present both a challenge and an opportunity for reduction of greenhouse gas (GHG) emissions.

From a global perspective, the communities, governments and construction industries of progressive cities overseas have taken on pioneering efforts to set low/zero-carbon targets and develop new zero-carbon buildings and low-carbon retrofits for existing buildings in an effort to combat climate change (NHBCF, 2011). The United Kingdom (UK) aims to have all new buildings achieve zero-carbon by 2019 (UKGBC, 2007). France has set a goal that all its buildings shall be energy-positive by 2020. Other European Union (EU) countries have also proposed absolute carbon emissions reduction targets of 30% to 40% by 2020. There is a increasing number of ZCBs around the world that respond to these low/zero-carbon targets. Examples include The UK's Beddington Zero Energy Development (BedZED), completed in 2002; Singapore's Zero Energy Building (ZEB) of BCA Academy, completed in 2009; Korea (Samsung)'s Green Tomorrow of Korea, completed in 2010; Taiwan's Magic School of Green technology in National Cheng Kung University, completed in 2011; Korea's Zero Energy Office Building developed by the National Institute of Environmental Research of Korea, completed in 2011; and Seattle's Bullitt Center, completed in 2012.

As for Hong Kong, its first Zero-Carbon Building (the ZCB), completed in 2012, is not only technically zero-carbon but is also energy positive. Commissioned by Hong Kong's Construction Industry Council, the ZCB was designed by an integrated team led by the Architect Ronald Lu & Partners (Hong Kong) Ltd. (RLP) in collaboration with Ove Arup & Partners Hong Kong Ltd. (Arup).

The building is a three-storey exhibition and education centre with an approximate footprint of 1,400 m^2. It showcases state-of-the-art eco-building design and technologies, with a 1.3 ha public open space for the neighbourhood.

Design work started in April 2011. Construction work began in July 2011 with site formation. This was followed by the foundation and superstructure in August 2011. The building was eventually completed in June 2012. The project team managed to deliver an unprecedented, first-of-its-kind sub-tropical zero-carbon building in Hong Kong within a 15 month project timeframe. Using the project as a reference, this paper aims to address the design approach and integrated project delivery of sub-tropical low/zero-carbon architecture for eco-efficiency in a high-density/high-rise context.

Design for Eco-Efficiency

Creating More with Less

The term "Eco-efficiency" was coined by the World Business Council for Sustainable Development (WBCSD) in its publication "Changing Course" (Schmidheiny, 1992). This concept was endorsed at the 1992 Earth Summit as a new business concept and means to implement Agenda 21 and sustainability in the private sector. In architectural design terms, the core objectives are:

1. Increasing quality: environmental quality of both indoor and outdoor environments for the well-being of occupants and ecological value of the land;

2. Optimising the use of non-renewable resources: reduced consumption of energy, material and water; and

3. Reducing environmental impact: heat island effect mitigation, reduction of waste etc.

This paper is structured to five aspects: Place, Process, Programme, People and Performance. It examines how the ZCB addressed the specific challenges and opportunities for its design for eco-efficiency.

Place

Sub-Tropical Urban Context

Hot, humid and wet summers, high road-side air and noise pollution, close proximity of high-rises and a lack of open spaces are some of the unique challenges of Hong Kong.

While there are many low/zero-carbon buildings in relatively cool or mild climates (typically designed to be tightly sealed spaces with little energy exchange with the exterior), there are relatively few examples in hot and humid sub-tropical climates such as Hong Kong.

ZCB is located at a site with an urban context typical of Hong Kong. The site used to be an open training ground for construction workers and was covered by a concrete slab laid on its raised platform. It is surrounded by high-rise commercial buildings that cast considerable shadows onto different portions of the site throughout the year.

The surrounding buildings have significantly affected urban wind conditions on site. Prevailing wind directions were taken from the MM5 data published by the Hong Kong government. From this data, it was concluded that the prevailing wind direction at the site is predominantly south-easterly throughout the year. In the summer months, some wind comes from the south west.

Surrounding streets are often jammed with busy vehicular traffic that generates considerable environmental nuisances.

Climate-Positive

People have a tendency to escape from Hong Kong's summer climate and environmental nuisances into enclosed buildings that are mechanically conditioned. However, blocking direct solar heat (reducing resultant temperatures) and creating breezy sites (increasing skin evaporation) could significantly improve people's psychological responses to climate. Such measures would promote outdoor living and enable outdoor areas to be used throughout the year.

The project team of the ZCB investigated the heat island effect of the site at the outset. On-site measurements had been taken prior to the commencement of construction work and confirmed that surface temperatures can reach between 40°C to 48°C at 1500hrs on a summer's day, largely because of the exposed impervious concrete ground slab and lack of greenery (Figure 1).

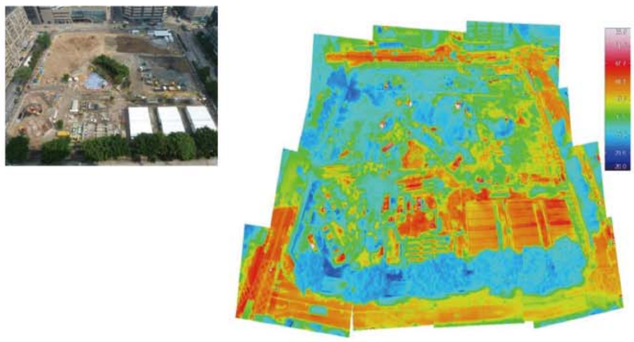

Figure 1 M100 Surface temperature contour of the project site at 1500hrs, 7 September 2011 (Source: CIC)

To mitigate the heat island effect, the project achieved a greenery coverage of approximately 50% with some 400 trees (more than 270 trees per hectare) as well as shrubs, turf and vertical greening. Plant species morphology was studied to review the form, growth rate, maturation sizes and to review the trees' shading effect on pedestrian and gathering areas. Large canopy trees were chosen and situated to offer shade to pavement, and provide a greater cooling effect through evapotranspiration compared to other planting. The majority of the greenery was placed to the south east of the site to serve as a "heat sink" to cool prevailing winds and protect the district against the heat island effect. In addition, the trees also serve as "carbon sinks" – each mature tree is estimated to absorb 23kg of carbon dioxide a year.

The project team further investigated the microclimate of the urban district to determine the siting, form and orientation of the building to capture potential solar and wind resources. The building is sited at the north-west corner of the site to minimise overshadowing from surrounding buildings as much as possible, in order to harvest renewable energy by photovoltaics (PV) (Figure 2). This location also allows the building, as well as the open space, to receive prevailing south-easterly winds throughout the year in this area of Hong Kong (Figure 3). The elongated and tapered form of the building minimises the area and glazing on its east and west facades and maximises solar capture for PV panels with its sloping roof of 17 degrees to 20 degrees.

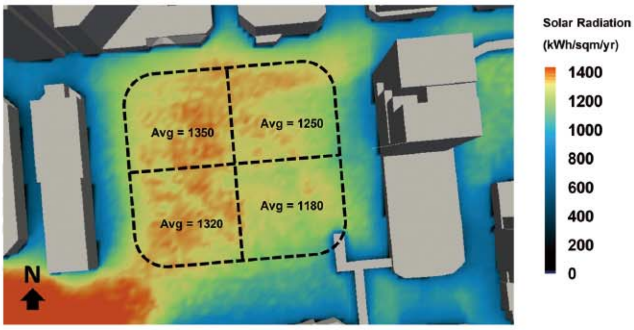

Figure 2 Solar irradiance study (Source: Arup)

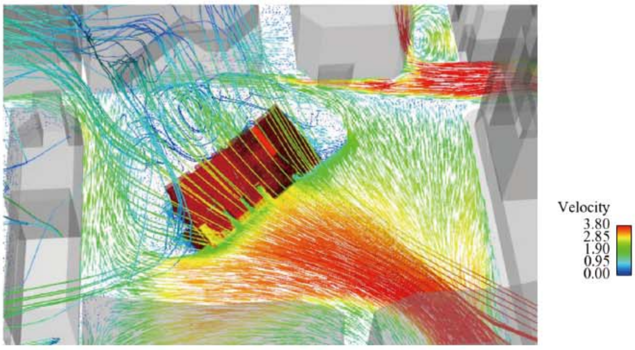

Figure 3 Urban wind study (Source: Arup)

Other sustainable site planning strategies, such as storm water harvesting and grey and black water recycling have been implemented to minimise the ecological footprint of site development.

Place-Making

Lively neighbourhoods and inviting public spaces promote people's health, happiness and well-being. An open plaza decked with eco-timber and its adjacent green terraces are planned within the featured "One-Planet-Living Loop" at the centre of the site. The public spaces are close to neighbourhood amenities (cafés, shops, toilets, shaded outdoor seating, etc.) and are very visible and easily accessible (adopting principles of universal design) from all entry points of the site.

With a view to screen off surrounding environmental nuisances caused by heavy vehicular traffic, and to minimise the carbon footprint of the construction process, the site was formed in a balanced cut-and-fill manner to create higher planting zones along the perimeters and a lower multi-purpose open space at the centre (Figure 4). The concrete debris salvaged from the demolition works was used in the gabion wall construction in the landscape areas. Such low-carbon interventions greatly enhance the environmental quality of the people's spaces.

Figure 4 Conceptual site section

Capturing Renewable Resources

An excess of solar gain will overheat outdoor spaces and increase cooling loads in buildings. If captured, however, solar power can be used to generate electricity. The site is surrounded by tall buildings, with overshadowing notably towards the south of the site, which is under the shadow of Megabox. The annual irradiance plot (Figure 2) indicated that to harvest renewable energy, an optimum location for the building was near the north-west of the site. When PV panels are positioned on an appropriate sloping angle on the roof, preferably in combination with "cool surfaces" and adequate ventilation to cool down the panels, they generate electricity, intercept solar heat and offer shade to the building. This location works with the optimum location for the drainage reserve, which places the building towards the north-west of the site where both solar and wind resources are most abundant. However, we note that despite these measures, this site is in an urban location and overshadowing is significant hence the solar reception is approximately 15% to 30% less than that of a site that isn't shadowed by other buildings.

Enhancing Ecological Value

Native plant species, preferably of diverse ecological communities providing local fauna with appropriate food sources and habitats, are generally considered to have higher ecological value. To this end, the urban native woodland was introduced as one of the site's key eco-landscape design features and is the first of its kind in Hong Kong. The woodland area accounts for approximately 20% of the site area and helps to regenerate local biodiversity in the urban area. Tree species were chosen from those found in local habitats and were selected based on three cardinal criteria: (a) diversity of mature tree size and form; (b) ornamental flowers; and (c) food and shelter to attract native wildlife into the city.

Other planting species in the landscaped area of the project are also predominantly of local origin. This is in line with the Guiding Principles on Use of Native Plant Species in Public Works Projects as promulgated by the HKSAR Government (Development Bureau, 2010).

The adaptability of the plant species and microclimate of the native species was studied to ensure the site conditions were suitable for the planting and to avoid excessive post-planting care and replacement planting in the establishment period.

Process

Defined Visions and Targets

Visions and targets for zero-carbon were adequately defined and studied for their feasibility, international protocols, and practices at the outset of the project. Design processes were outcome-driven and decisions were largely made on a performance-basis rather than on a first cost or aesthetic basis.

The definitions of zero-carbon buildings proposed by The United Kingdom Green Building Council (UKGBC, 2008), which are among the most commonly used definitions, have been referred to in the project. The ZCB is connected to the local grid. This allows energy to be exported and the production of on-site renewable energy offsets the power consumed from the grid on an annual basis. Within the current economical and technological constraints, this arrangement is defined as Type 2 zero-carbon by the UKGBC (2008), and is in line with the definition of Net Zero Energy Building (ASHRAE, 2008), Carbon Neutral Building (Arup, 2008) and Levels 5 and 6 in the Code for Sustainable Homes (UK Communities and Local Government, 2013).

The ZCB took its initiative one step further and went beyond the scope of the UKGBC definition of net zero-carbon by exploring the potential to produce sufficient on-site renewable energy. This would offset the ZCB's embodied energy, created during its construction process and embedded in its major structural materials, as well as the energy use in the operation phase, making the site "energy-positive". A zero-carbon design hierarchy is formulated with the first priority placed on energy demand reduction through extensive use of state-of-the-art passive design strategies and use of low embodied carbon materials/construction.

The embodied carbon footprint of materials is lowered by adopting dematerialisation in design and the use of recycled/regionally manufactured materials (examples include eco-pavers, concrete mixes with a high percentage (25% to 35%) of pulverised fuel ash (PFA) and recycled aggregates, and use of construction and demolition waste salvaged on-site).

Integrated Process

The integrated design team, comprising expert professionals with multi-disciplinary knowledge from RLP and Arup, had partnered successfully in previous projects. Open and interoperable data exchanges, based on disciplined and transparent data structures, facilitated a swift design process (AIA, 2007) to evaluate solutions with respect to defined performance targets.

Shaping the ZCB to utilise solar and wind resources in the Hong Kong context was the essence of the project. The use of Building Information Modelling (BIM) technology expedited the collaborative design process to achieve carbon neutrality. The resultant structure's curvy form serves the multi-purposes of: maximising solar reception for PV generation, creating pressure difference that drives natural ventilation, reducing solar heat gain, and maximising daylight penetration.

Information on avant-garde green features such as wind catchers, a biofuel chimney, an active skylight and microclimate monitoring stations was consolidated in BIM, which enabled the design team to work out their strategic locations, deliberate installation details, and unprecedented mechanical, electrical and plumbing coordination of green technologies.

In search of a cut and fill balance, BIM validated the optimum excavation for footings and basement plant rooms, and the strategic formation of an undulating landscape profile to benefit microclimatic conditions.

The complex construction of the curvy roof was resolved by leveraging BIM and RLP's in-house parametric design expertise, through the use of the technologies, and early knowledge contributions from contractors. The three-dimensional setting-out points of the roof were determined for concreting the curvy building structure and for precise assemblage of undulating PV panels to synchronise information and coordinate complicated construction interfaces in BIM before actual construction.

Programme

Seizing Green Potential

Accommodations in the functional programme requirements were carefully studied to seize green building design potential. Design for flexibility/adaptability and harnessing passive design potential for natural ventilation and daylight were critically reviewed. Specific counter-proposals for functional programme modifications were carried out by the project design team and delivered to the client with detailed justifications. Examples include:

- Entrance Lobby: originally, the brief required a 50 m^2 internal space. To enhance the sense of arrival and provide a more airy orientation space for visitors, the entrance lobby and reception was proposed as a transitional space, that is fully opened on both sides for high visibility of the landscape and high air-ventilation permeability. The project team did not suggest air-conditioning for this space. High spatial adaptability was adopted in the design due to its openness, and its central location adjacent to the eco-plaza, multi-purpose room, temporary exhibition area and the main permanent exhibition space. To better serve as a flexible space to support the surrounding functions, the project team suggested that this area be enlarged to 100 m^2.

- Vestibule for Cool-biz Dress Code: a vestibule with lockers was proposed next to the entrance lobby so visitors could learn about the green dress code and dress down according. Self-explanatory mega-graphics were designed to illustrate appropriate clothing levels in different seasons.
- Carbon Footprint Indicator: a real-time LED indicator was proposed near the entrance lobby to show the cumulative energy consumption, renewable energy generation, and the resultant carbon footprint.
- Temporary Exhibition Area: to provide a platform for stakeholders to showcase the latest green products and a portfolio for zero/low-carbon building development, a temporary exhibition zone of about 100 m^2 was proposed to be added next to the entrance lobby. The area is well integrated with the entrance lobby and is also fully ventilated on both sides. High visibility of the area will enhance its usage.
- Multi-Purpose Room: the multi-purpose room was designed to adapt to a wide range of functions including a zero-carbon exhibition, seminars/conferences, eco-weddings, and more. To maximise spatial adaptability, the room was designed to be expandable on three sides, with sliding folding partitions towards the entrance lobby on the west, the semi-outdoor spaces on the east, and on the south. Operable partitions were also proposed to sub-divide the room if needed. In the expanded mode, the covered area of the multi-purpose room can be enlarged from 260 m^2 to 400 m^2. In the partitioned mode, each sub-divided room can still achieve effective natural cross ventilation. To shield the multi-purpose room from noise from the street and eco-plaza, a green wall that is lifted above ground intercepts noise, but allows cooling breezes to pass through.
- Eco-Office: an open plan office was proposed on the west wing ground floor of the ZCB as a living showcase of a green office. It can be sub-divided into two sub-offices by flexible partitioning. A tailor designed Building Environmental Performance Assessment Dashboard (BEPAD) was proposed by the project team as an interactive display of the real-time environmental performance and carbon footprint of the building.
- Permanent Exhibition Space: the space is located on the ground and mezzanine floors of the west wing to house the interactive exhibits themed on passive, active and renewable measures of the ZCB. Plant rooms in the basement housing the green active systems of the building are also regarded as permanent exhibits. Barrier free access is provided as the lift stops on all floors including the basement floor. To create a pleasant tour experience, visitors can see the contents of the plant rooms through full-height glazed walls in a sunken garden on the basement level as shown in Figure 5.

Figure 5 Sunken courtyard at basement plant room level

- Eco-Home: the eco-home was proposed on the mezzanine floor to simulate an above ground dwelling comparable in size with a standard Hong Kong apartment. It is approached from a spacious semiopen terrace where visitors can have a short briefing or debriefing before or after their visit.

People

Integrated Teamwork

The project was steered by a special task force formed under CIC. This task force comprised experts, academics, and practitioners in low/zero-carbon development. An in-depth liaison was maintained with the design team throughout the project, to agree on the vision, targets, strategies and design. This was pivotal to the success of the project. It relied on the continual exchange of ideas, open sharing to define objectives and evaluate outcomes based on a consensus, and on a collaborative approach based on trust and mutual respect, as opposed to some traditional hierarchical approaches in other projects.

RLP proposed to CIC the adoption of Management Contract procurement at the outset of the project to facilitate early involvement of contractors and suppliers in the design process. Early discussions/resolution of pre-construction issues with input from the management contractor were possible and informed the design process. This proved to be vital to the completion of the project within such a fast track time frame.

Early and Continual Stakeholder Engagement

District and neighbourhood consultations took place within one month of the project's commencement to gauge neighbourhood expectations and to create dialogues. This promoted support from the neighbourhood for the project. For construction industry stakeholders, engagement workshops were held to gather their comments and suggestions at the feasibility stage. Responses to stakeholders' suggestions after detailed technical review were documented for further deliberation with the CIC Task Force to determine a way forward.

Emphasis on Well-Being

Indoor environmental quality is boosted through the cross-ventilated and daylit design, which also features glare and noise control. Visibility in and out of the building, to and from the landscape area and the neighbourhood was achieved through the use of glazed walls, protected by external shades.

Hub for Cultural Shift

To support the vision of the ZCB as a hub to drive a cultural shift towards sustainable design and construction for the industry, and sustainable living for public at large, the building is expected to cater to 40,000 visitors per year. This implies a significant internal thermal load from visitors which will be significantly higher than at other existing overseas ZCBs. The passive design and active systems for environmental control have to be of high performance to cater to the load.

To effectively serve as an educational tool for sustainable living, the eco-landscape design has integrated information graphics with "One Planet Living" principles (Desai, 2009). At the centre, shaded activity spaces energize and celebrate eco-events. Along the "One Planet Loop", visitors can learn about the principles as demonstrated by the ZCB on zero-carbon, zero-waste, sustainable transport, sustainable materials, sustainable water, local and sustainable food, urban woodland, green culture, equity and local economy, health and well-being.

To reinforce the message that occupant behaviour is a critical factor in achieving carbon neutrality, the ZCB is the first building in Hong Kong that requires compliance of a "Cool Biz Dress Code" for visitors to foster a cultural shift towards a more sustainable way of living.

Performance

High-Performance Passive Design

The synergy and integration of passive design, active systems and renewable energy technologies has always been the emphasis of the project. With the objectives of this paper, only the passive design aspects of the project are examined in detail. Nevertheless, the element of integration with active systems and renewable energy technologies adopted will be highlighted as appropriate.

The passive design strategies of the ZCB are estimated to reduce energy consumption by 20%, as compared to current building industry benchmark. These include the following:

Optimization of Building Orientation and Form

The orientation and shape of the building represents an optimised shape in response to the local microclimate. The main southeast facing facade presents ample opportunities for capturing wind flow for natural ventilation. The high sun angle over this portion of the envelope is well shaded by structural overhangs. The gradually sloping roof (17 degrees to 22 degrees) maximises solar capture for PV panels (Figure 6).

Figure 6 Building section for tapering built form

Angling the building with a sloping sectional profile also reduces the area of the south façade and increases the north frontage. This reduces solar heat gain to the south and increases access to daylight from the north.

The built form, with a large void deck at the entrance hallway and temporary exhibition area, helps minimise the cooling load during peak summer periods. The entrance lobby is fully opened on both sides and does not require any air-conditioning installation. The tapered sectional form also works with the prevailing wind, creating larger negative pressure on the leeward facade and to induce ventilation through the building when there is wind. With the tapering double volume, a strong stack effect also creates air movement when there is less wind, without imposing visual bulk as seen from the landscape area and neighbouring buildings.

Daylight is harvested from the double height north facing windows to minimise the use of artificial lighting. The sloped ceiling amplifies the interior brightness through reflection. This is coupled with a dimming system that adjusts the level of artificial lighting to minimise energy consumption. To further enhance air and light penetration, recesses were introduced along the southeast façade (Figure 7).

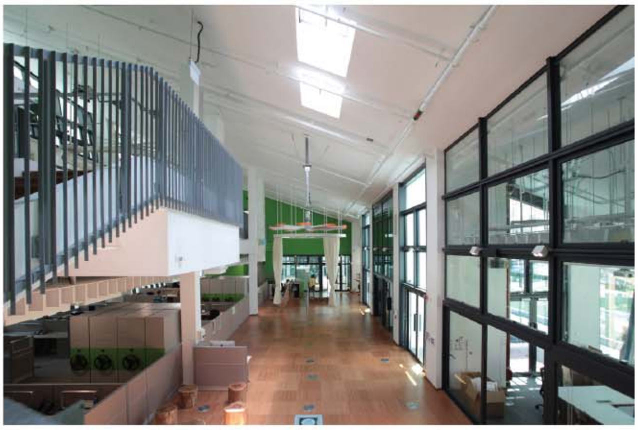

Figure 7 Interior of exhibition space

Design for Hybrid Ventilation

The design has the flexibility to switch between a tightly sealed air-conditioned environment and a highly porous cross-ventilated mode with low thermal storage capacity. The objective is to create a gentle but uniform air movement throughout the building to counter the often high humidity environment of Hong Kong.

In the hot months, envelope air tightness is particularly important to reduce air leakage in the Hong Kong climate because dehumidification of high humidity infiltration has a disproportional impact on the size of a mechanical plant and its energy use.

In the cooler months there is good potential for buildings to be naturally ventilated. The ZCB features an open plan cross-ventilated layout. When used in conjunction with High-Volume-Low-Speed (HVLS) fans – it promotes a gentle and uniform air velocity throughout the building. This minimises the duration of mechanical cooling during non-summer periods and can effectively counter the effects of humid weather (effective for approximately 30% to 40% of the year).

High-Performance Building Envelope

Façade thermal performance has a significant impact on the cooling load and energy performance of the building. The solar strategy and window-to-wall ratios (WWR) for each orientation of the respective facades are optimised for daylighting and viewing without excessive ingress of heat. A relatively higher glazing ratio (approximately 40%) for views and daylight was proposed for the street façade facing Sheung Yuet Road. The low-angled sun in the summer afternoons will be blocked by surrounding buildings and will not cause glare in the building. The southeast facade has a deep overhang (about 45 degrees) to shade the summer sun while allowing good views towards the landscape area. High performance glazing, with a fritted pattern, controls the opacity of the two facades to avoid heat gain. External fins and vertical planting are also integrated. The facade is painted with "cool paints" that reflect solar heat. The roof is shaded by PV and a green roof. As a result, the building achieves an OTTV of 11W/m^2, which is about 80% lower than the current statutory threshold, thereby reducing the cooling load during peak summer periods.

For natural ventilation, high level windows are controlled automatically by the Building Management System (BMS) to coordinate its operation with the air-conditioning strategy. Inhabitants control low level windows manually, so they may tailor the amount of ventilation and wind-speed at the occupied level.

Thermal Storage/Inertia

The operation of the exhibition and multi-purpose space means the building will experience fluctuating loads. Exposed concrete slabs and cladding act as thermal storage to regulate temperatures in these spaces, to absorb temporarily intensive loads (tour groups), and they purge the excess heat during load occupation time through natural ventilation.

Design for Interactive Monitoring

ZCB is subject to comprehensive monitoring to optimize its performance. The results are displayed interactively on a 3-D model of the building in real-time. More than 2,800 sensing points were integrated into the building to report on every aspect of building performance. CO_2 sensors monitor the air quality within occupied spaces and adjust the amount of fresh air provided to each space as required. Four microclimate monitoring stations were placed on and around the building, to enhance our understanding of how the building performs and interacts with its surroundings, and to optimise the operation of windows and their interface with the air-conditioning systems. This is particularly important in the high-density context of Hong Kong (Figure 8).

Figure 8 Building Environmental Performance Assessment Dashboard

Discussion and Conclusion

The ZCB is a milestone and one important step for Hong Kong towards a low-carbon city. It has been designed at the outset with clear objectives of eco-efficiency in mind.

This paper investigated how the ZCB has addressed the challenges of the sub-tropical urban, site and climatic contexts to create inviting public spaces, to enhance the microclimate of the immediate neighbourhood and the ecological value of the site, to reduce environmental impacts with optimal use of resources, and how the detailed bioclimatic studies of the site have informed the decisions on building disposition to best utilise the renewable resources of the site.

The collaborative and integrated design process was made possible through effective engagement with the client, key stakeholders and project team in the design and construction to define targets, evaluate outcomes and refine proposed solutions with a clear set of quality and performance objectives. By leveraging BIM and parametric design technology, the project designs evolved and data was shared in a swift, open and structured manner. Management Contract procurement also helped to engage contractors and suppliers earlier in the detailed design stage to have pre-construction input on various design issues.

The brief was critically reviewed and the project design team had agreed with the client on modifications of the functional programme to better seize the potential for passive design and spatial flexibility.

The success of the project will be largely determined by how well the building will perform in terms of carbon neutrality and how the public, as well as the industry stakeholders, are engaged in sustainable living, design and construction. The passive design, working hand in hand with the active systems and renewable energy technologies of the building, is estimated to reduce building energy consumption by 20% as compared to current building industry benchmarks. On top of the green building design measures, the building is designed to be a living tool to educate visitors through an interactive real-time performance dashboard, and integrated educational graphics and displays, to motivate people to embrace positive behavioural change and low-carbon living.

Despite its success, as demonstrated by the recognition of its achievements by reputable institutions, the ZCB is subject to a number of limitations as a demonstration project for carbon neutrality. These include:

1. Applicability of the demonstration project/viability of zero-carbon for other building uses and types: further studies/research/pilot projects can make reference to the design approach and methodology of ZCB, and apply the necessary modifications for mixed use larger scale/high-rise development projects in Hong Kong or overseas;

2. Development of local/regionally manufactured building materials and green building systems: more research and development is needed to foster and increase the supply of quality and cost-effective green building products with third party certification, this will greatly improve the financial viability of low/zero-carbon developments;

3. Integrated project delivery by refining the procurement model: traditional design and contract procurement methods should be reviewed for their effectiveness in delivering high-performance multi-disciplinary projects with clear objectives on exemplary sustainable design targets. Multi-level and early contribution of expert knowledge and information sharing by all project team members is crucial to achieve high eco-efficiency and cost-effectiveness; and

4. Policy to mandate low/zero-carbon developments, supported by clear definitions of zero-carbon by the industry. There is a need for a stronger push by the government and pull by the green building industry for market transformation is vital for a city wide low/zero-carbon building movement.

Acknowledgements

The CIC ZCB project could not be delivered with success without the enormous support and contribution from our enlightened client, all involved parties and the dedicated project team.

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MK Leung, architect, LEED AP, BEAM Pro, was educated in both Hong Kong and UK and has over 20 years of professional experience. He is a recognised pioneer in green architecture and sustainable design and specialises in integrating the principles of sustainable design in master planning, new construction, urban regeneration as well as research projects. He is also actively involved in government committees, academic and related professional bodies. MK is a sought-after conference speaker on sustainable design.

External vertical sunshading fins on northern facade

The open entry area facilitates cross ventilation

Cross ventilated open plan layout

Tapered built from

Key Passive Design Strategies of the ZCB

Situated on the north-west corner, the building and its surrounding open space receive prevailing cool south-easterly winds throughout the year. This location also minimises overshadowing from adjacent buildings. The elongated and tapered built form of the building along the east-west direction helps to maximise solar capture, natural ventilation and daylighting in the building. Low-E performance insulated glass, deep overhangs, careful window placement and a highly insulated roof work in combination to reduce the overall energy needs for the building.

Building Management System (BMS) control of high level windows with manual override

Deep overhangs and trellises on the south facing facade to minimise summer sun penetration

THE ZCB - HONG KONG'S FIRST ZERO CARBON BUILDING AND ITS KEY CARBON NEUTRALITY STRATEGIES

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Summary

In Hong Kong, buildings consume most of the energy and are the major contributor to Greenhouse Gas (GHG) emissions. To this end, the Hong Kong Construction Industry Council (CIC) has introduced a series of initiatives to reduce GHG emissions from the construction industry. One such initiative is the development of the first Zero Carbon Building (the ZCB) in Hong Kong. Located in Kowloon East, the ZCB integrates state-of-the-art design and technologies, including passive design, active systems and renewable energy systems, with a view to achieving zero carbon emissions. The main objectives of the ZCB are to showcase these state-of-the-art eco-building design and technologies to the construction industry, both internationally and locally, and to raise awareness of sustainable living in Hong Kong. This paper highlights the key engineering considerations of the ZCB design.

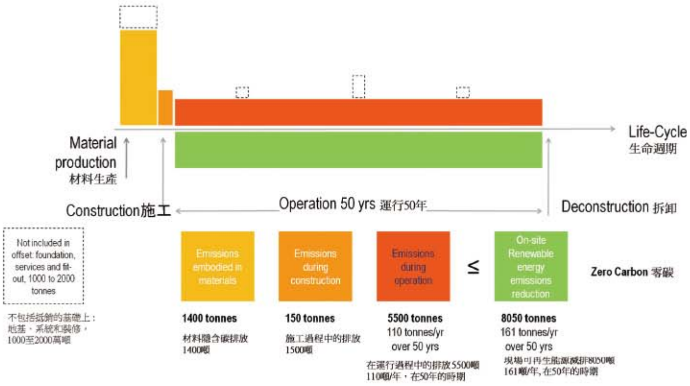
Figure 1 Modeled impression of ZCB

Introduction

This project is an attempt to create a new kind of zero carbon environment that integrates work, education and social well-being. The ZCB is designed to address specific local challenges in achieving zero carbon and is fitted out with more than 80 environmental features that will allow local and international researchers to explore and understand future design practices. The total site area is approximately 14,700 m^2, including the ZCB's footprint of 1,400 m^2. The three-storey building comprises an exhibition and education centre, an eco-home show room, an eco-cafe and a multi-purpose room. The accompanying open space is the first designed native urban woodland in Hong Kong. The venue will also be open to the public for "green weddings" and other sustainable living experiences.

Overall Objective

Carbon Neutral Energy Positive – The ZCB has a carbon neutral mission. The ZCB is connected to the local power utility grid and produces on-site renewable energy for offsetting site energy consumption supplied by the grid on an annual basis. The ZCB also goes beyond the common definition of a Zero Carbon Building by exporting its surplus renewable energy to the local grid to offset the embodied energy of its construction process and major structural materials. Renewable energy is generated from on-site renewable energy systems including a biodiesel tri-generation system and photovoltaic (PV) systems.



With the on-site renewable energy systems, the estimated net CO_2 reduction is 8,050 tonnes (over a 50-year period)

Figure 2 Carbon dioxide (CO_2) reduction over a 50-year period

Zero Carbon Hierarchy

The Design Process of the ZCB Adheres to the Zero Carbon Hierarchy – It makes reference to the current best practice building energy codes as a starting point (EMSD, 2012). From there, passive design opportunities for reducing the reliance on mechanical systems are explored. Under circumstances where mechanical systems are required, we ensure that systems of the highest efficiency are selected. Finally, any unavoidable energy consumption is met through on-site renewable means.

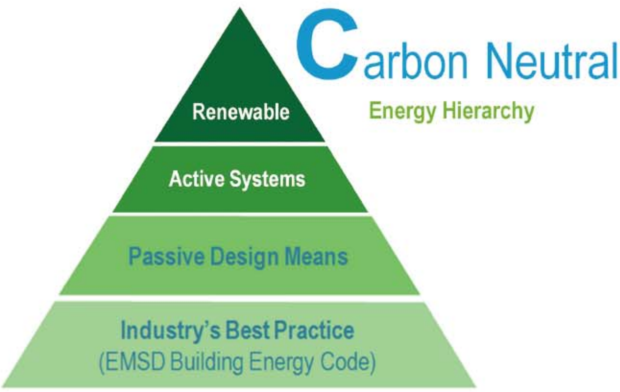


Figure 3 The Zero Carbon Hierarchy

Highlights

This section is a brief overview of the key design features that contribute to the zero carbon operation of the ZCB.

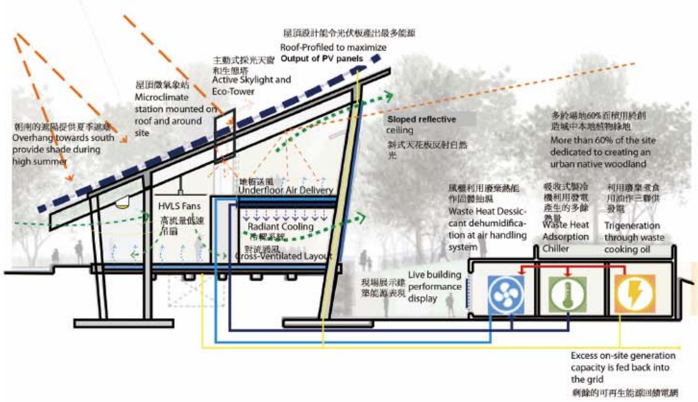


Figure 4 Key design features of the ZCB

Passive Design

The passive design of the ZCB focuses on three key areas:

- minimising the cooling load during peak summer periods;
- minimising the duration of mechanical cooling during non-summer periods;
- minimising the use of artificial lighting through the appropriate introduction of daylight.

Building Orientation – Optimisation of building orientation and form to maximise natural ventilation and daylight penetration.

High Performance Envelope – Minimises heat gain (Overall Thermal Transfer Value (OTTV) < $15W/m^2$, the conventional value being $24W/m^2$), while allowing cross ventilation.

More than 50% Green Coverage and Green Walls – Reduces the urban heat island effect.

Cross Ventilation and High Volume Low Speed Fans – The building is designed to address specific environmental challenges of Hong Kong's climate conditions. It features an open plan, cross-ventilated layout, that when used in conjunction with High-Volume-Low-Speed (HVLS) fans, promotes gentle and uniform air-velocity throughout the building to effectively counter the effects of the often humid weather (effective for approximately 30% to 40% of the year) (ASHRAE, 2010). A typical Zero Carbon Building, by way of contrast, commonly built for use in northern climates, is chiefly designed to be a tightly sealed box with little environmental exchange between the interior and exterior.

Automatic Windows and User Control – A number of high-level windows are centrally controlled and their operation is coordinated with the building's air-conditioning stratagem. There are also user controlled low-level windows designed to tailor for the amount of ventilation and wind-speed at the occupied level.

Microclimate Monitoring – A centralised Building Management System (BMS) controls the "passive operation" of ZCB. The system monitors external conditions to optimise the operation of windows and the building's interface with its air-conditioning systems. Four microclimate-monitoring stations are placed on and around the building to enhance our understanding of how the building performs and interacts with its surroundings. This issue is of particular importance and interest in high-density Hong Kong.

Natural Lighting – Daylight, with little of the associated heat, is diffused through the ZCB's large north facing facade. The sloped ceiling amplifies the interior brightness through reflection. This is coupled with a dimming system that adjusts the level of artificial lighting to minimise energy consumption.

Light-tubes – The ZCB incorporates daylight harvesting devices that direct daylight deep into the core of the building.

Active Systems

High Temperature Systems – The ZCB's air-conditioning systems are advanced. They incorporate a high-supply air temperature system that includes under floor air supply, a radiant system, and desiccant dehumidification. To achieve the desired room conditions of 26°C, 55% Relative Humidity, a conventional system would overcool the supply air (to 10°C-14°C) to achieve dehumidification. In the ZCB's advanced design, humid fresh air is pre-treated through a desiccant dehumidification process. As a result, the air and coil temperatures can be significantly higher, reducing the demand load on the chillers.

Task Lighting – Rather than a stark contrast between uniformly lit areas to high levels of brightness, most of the building will be illuminated to approximately 200 Lux (appropriate for circulation), while task lighting is provided in areas where work with a higher level of concentration occurs (office desk, displays etc).

Carbon Dioxide (CO_2) Sensors – Cooling and dehumidifying fresh air requires large amounts of energy. The ZCB's CO_2 sensors monitor air quality in occupied spaces and adjusts the amount of necessary fresh air provided to each space.

Occupancy and Daylight Sensors – Occupancy sensors are adopted to turn off lighting in empty office areas. Spaces are divided in zones with occupancy sensors focused on partitioned rooms that are expected to be empty during specific periods. Daylight sensors are provided on the perimeter of office areas for monitoring daylight levels and dimming associated lighting to desired levels according to the pre-set programme of the dimmer-rack system.

Active Skylights – A controllable skylight allows users to adjust natural daylight levels with louvre blades.

Low Energy Office Equipment – Numerous requirements are specified for the office occupants in terms of equipment efficiency and usage.

Comprehensive Monitoring – More than 2,600 sensors are built into the building to report on every aspect of building performance. The results are displayed interactively on a 3-D model of the building in real-time.

Renewable Energy

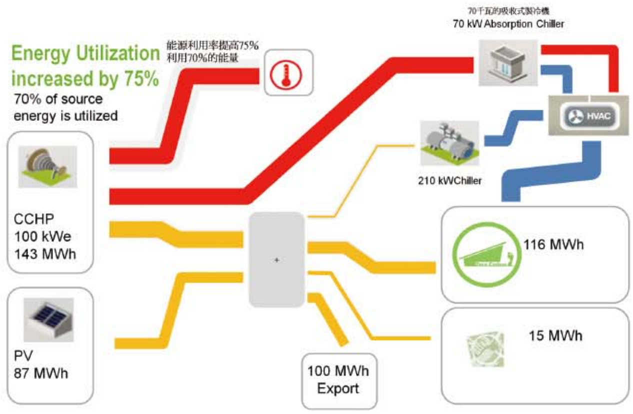


Figure 5 Renewable energy systems

Energy Cascade – The ZCB design addresses the short-comings of conventional electricity supply, which is inherently inefficient due to the high rate of heat rejection – only 40% of the source energy is captured. At the ZCB, thermal energy from the combustion of biodiesel is captured in an energy cascade that first uses the highest grade heat for electricity generation, then for adsorption cooling and desiccant dehumidification. Under this scheme, 70% of the fuel energy is captured.

Grid Feed-In – This is the first building in Hong Kong to export surplus renewable electricity to the grid.

Biodiesel – The large scale use of biodiesel, to EN 14214 standard, as a renewable fuel for tri-generation is also a first in Hong Kong. In conventional systems, the combustion of fossil fuel releases CO_2 into the atmosphere that would otherwise have remained in the ground undisturbed. In the case of biodiesel, the CO_2 emitted during its combustion will be absorbed via photosynthesis by plants, producing the feedstock for making biodiesel. For biodiesel produced locally in Hong Kong, the feedstock is waste cooking oil. Typically, this waste stream is sent to landfill. As a result, the emission factor from waste cooking oil is very low, since it displaces the combustion of fossil fuel and circumvents methane gas generation at landfills.

PV Panels – The ZCB features 1,015 m^2 of polycrystalline panels that produce a high output. BIPV panels are integrated into the building fabric (25 m^2) where natural light penetration is desired. The design also showcases the new ultra light weight cylindrical Copper, Indium, Gallium and Selenide (CIGS) technology.

Solar Thermal System – The system is used to produce hot water at the eco-café.

Building Load Profile – The typical daily load profile estimates (for summer and winter) are as follows:

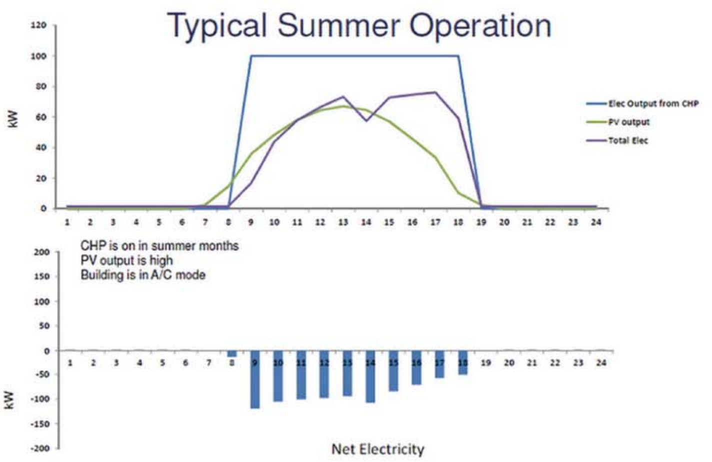
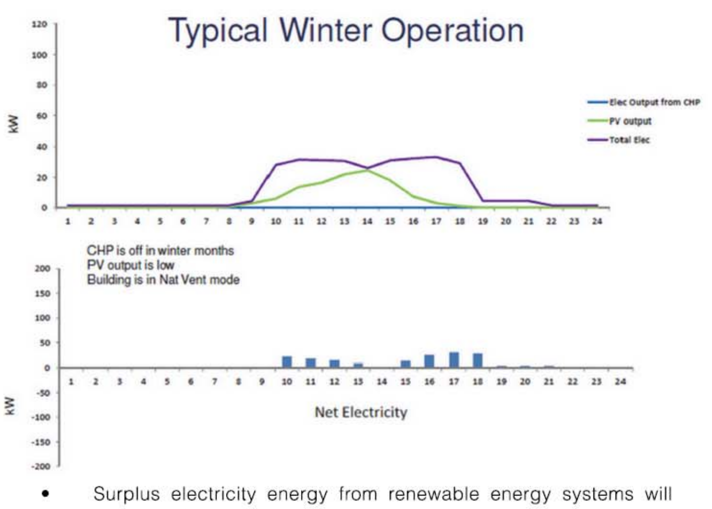


Figure 6 Building loads in summer



- Surplus electricity energy from renewable energy systems will feed into the utility grid on an annual basis.

Figure 7 Building loads in winter

Embodied Carbon

Low Embodied Emission Design – The ZCB adopts a structural design that minimises the use of materials and embodied emissions.

Recycled Materials – Recycled materials such as tio-stone, 35% pulverised fuel ash (PFA) concrete, aggregates and metals are used wherever the design and schedule allows.

Carbon Credits for Rental and Commercial Activities – Carbon credits can be purchased for large scale commercial activities on site to further offset the building's carbon footprint.

Conclusion

Performance

The site is expected to consume approximately 130MWh of energy each year (~ 70kWh/m^2/year for building-related energy). On site renewable energy is expected to supply approximately 230MWh of electricity per year, of which 100MWh will be exported to the utility grid. Not only will the operation of the building be zero carbon, the energy export will also offset more than 2,000 tonnes of CO_2e over its 50 year life cycle. This is approximately equivalent to the embodied carbon in the building's major structural components.

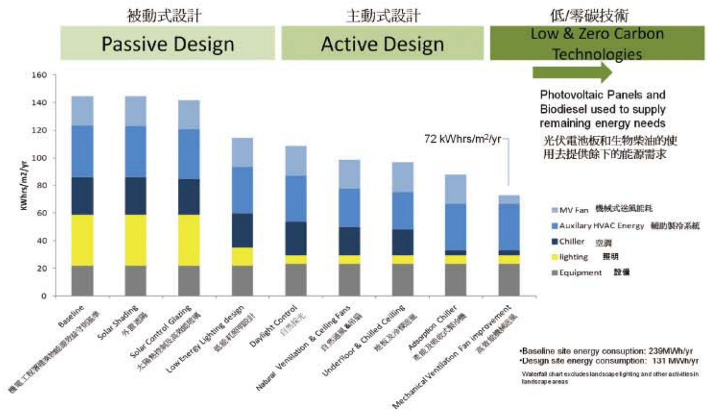


Figure 8 Predicted building-related energy consumption

Lessons Learned

Designing for Local Context – While there are many zero carbon buildings in relatively cool or mild climates (typically designed to be tightly sealed spaces with little energy exchange with the exterior), there are relatively few examples in hot and humid sub-tropical climates such as Hong Kong. For ZCB, the design team experimented with a building that has the flexibility of switching between a tightly sealed air-conditioned environment, to a highly porous, cross-ventilated mode with low thermal storage capacity. The objective is to create gentle, but uniform, air-flow through the building to counter the high humidity of Hong Kong's climate.

Biodiesel – The decision to incorporate biodiesel tri-generation as a zero carbon fuel source was the subject of much debate. While living within the solar or wind "footprint" of the site is a lofty ideal, the requirements for flexible use of space that can accommodate different commercial activities meant that other fuel sources with higher energy density had to be considered. The decision was aided by the fact that biodiesel is produced locally in Hong Kong, with waste cooking oil as feedstock. Typically, this waste stream is sent to landfill. The emission factor of biodiesel from waste cooking oil is therefore very low since it both displaces the combustion of fossil fuel and simultaneously prevents methane gas generation at landfills.

ZCB is expected to cater to 40,000 visitors per year for a wide range of activities including: Zero-carbon exhibition tours, seminars and conferences, and eco-weddings. Office space for approximately 30 permanent occupants is also included.

Acknowledgments

The author gratefully acknowledges the design contributions of Ronald Lu and Partners (architectural design) and URBIS (landscape design). This project was funded by the Construction Industry Council.

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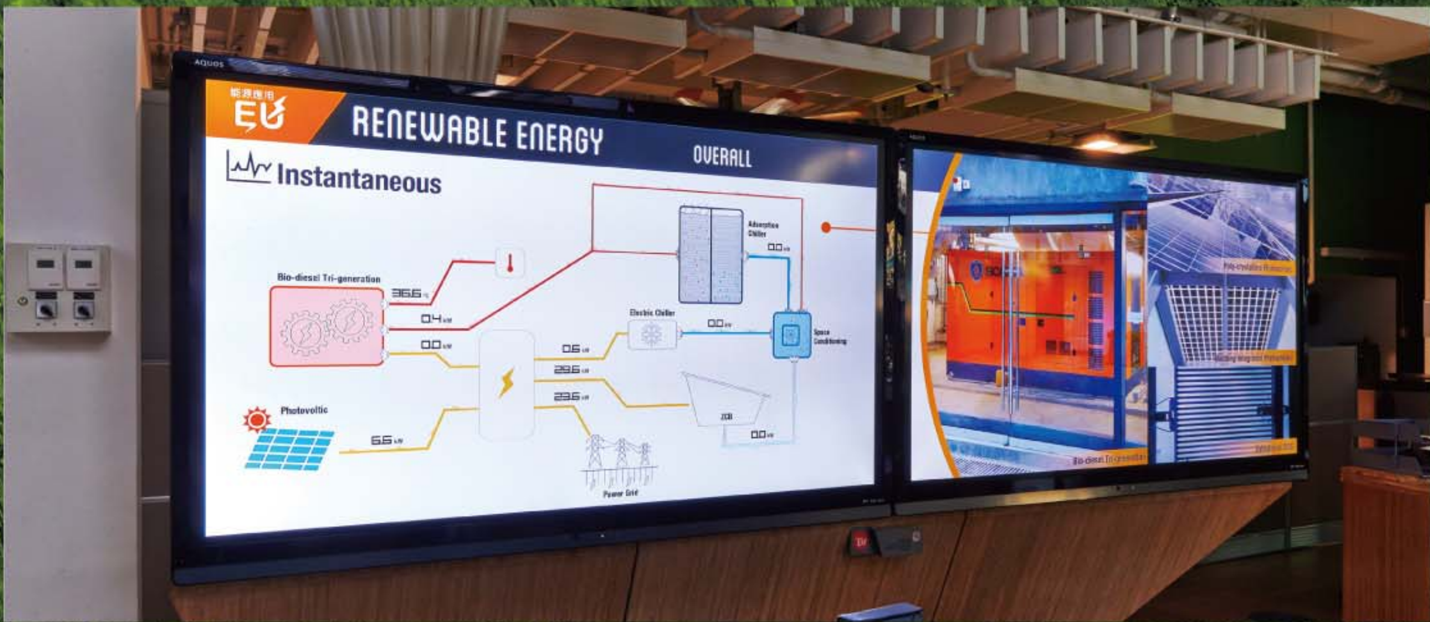
Dr Raymond Yau is Arup Fellow and Director of Arup Hong Kong. He is a building services engineer and building sustainability consultant who has more than 26 years experience in the integrated design of sustainable and environmentally responsive buildings and sustainable building physics. He is the project director of Engineering Consultant Arup, responsible for the total engineering design of the CIC Zero Carbon Building in HK. Many of his projects have won Green Building Awards or Sustainability Recognition such as Kansai International Airport Terminal, CIC Hong Kong's First Zero Carbon Building and Beijing Parkview Green. Dr Yau has been awarded Principal Innovator of the Champion Project CIC Zero Carbon Building under the Construction Category of the Hong Kong Institution of Engineers Innovation Award for Engineering Industry 2013.

Under floor displacement system cool occupants by convection

The real-time carbon footprint, building energy consumption and renewable energy generation are on public display

Chilled beams cool occupants via radiant cooling



Building Environmental Performance Assessment Dashboard (BEPAD) displays real-time data as monitored by the Building Management System

Key Active Design Strategies of the ZCB

Coupled with natural ventilation is an air-conditioning strategy to suit the hot humid Hong Kong climate. The ZCB's cooling strategy comprises a combination of radiant cooling via chilled beams, convection cooling through an under floor displacement system and high-volume-low-speed ventilation fans and a desiccant wheel to separately handle the removal of humidity from incoming air. This process allows the air and coil temperatures to be significantly higher without the need to overcool the air for dehumidification thereby reducing the cooling load and energy use in the building.

Natural daylight penetration to the interior of the building is controlled through an active skylight combined with sensor controlled artificial lighting and an adjustable dimming system. Building systems performance is balanced through the Building Management System which acts as the interface for the information collected from the 2,800 sensors located throughout the building.

High Volume Low Speed fans move a large amount of air at low speed

LEADING TO PROJECT SUCCESS - MANAGING EXPECTATIONS

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Summary

Seeking client feedback on consultancy services and persistently looking for improvement are now a standard procedure in companies. When it comes to the question of how clients appreciate the services they have been provided, or how successfully a project was delivered, scores sometimes end up a bit lower than our expectation and lower than other considerations of competency or staff friendliness. This leads us to ask: Are client expectations too high, or are we not trying hard enough? Whatever the case, the situation can be improved through the proper and systematic application of project management processes to achieve better end results.

Recent research done by the Project Management Institute (PMI) indicates that effective stakeholder communications lead to an effective project outcome and improves an organisation's performance. Good project management is meant to ensure that there are no surprises.

This paper will discuss the project management processes in the construction of the ZCB. It will explain the project's successful outcome in terms of expected quality and client satisfaction.

Keywords

expectation management, stakeholder engagement, communication management

Introduction

Whether a project is successfully delivered is often measured against a set of parameters. Basic parameters are time, cost and quality. Time and cost are parameters that can be quantitatively assessed against the original targets set at the beginning of the project. Quality, on some occasions refers to the client's satisfaction, is always a subjective measurement, resulting from different opinions governed by different perspectives.

The Hong Kong Zero Carbon Building (the ZCB) project was delivered in an extremely short period in just 14 months from design to hand over and tested against the application of technologies new to the construction industry. The project involved larger parties than are usually involved in a project of comparative size. In this scenario, effective communication among project team members and providing timely and clear communications to relevant stakeholders was vital in leading to project success.

From Inception to Handover

Almost every project originates from a problem or a need to which a solution is created and implemented.

In procuring a project team to deliver a project, the sponsor who is usually also acting as the client, will issue a Request for Proposal (RFP). An RFP is an invitation for tender submissions for the consultancy services to deliver the project. In writing up the RFP document, it is common that the client already has an intended solution in mind, and this solution is likely derived from his/her own experiences and perspective. It is very important that the RFP can truly reflect the clients' requirements and effectively relate to the consultants.

On receiving the RFP, consultants also have their own initial ideas of a solution, generated from their own interpretations of the written document and their previous experiences.

It is almost certain that the solutions have different sets of assumptions, and – at this point – are not likely to be identical. If the project proceeds directly into the implementation stage from here, it is likely that misunderstandings will accumulate. These misunderstandings may snowball and result in arguments which gradually creates a sense of overall disappointment of the project team – even for a very simple project of a short duration. Therefore, the project has a higher potential for failure than for success.

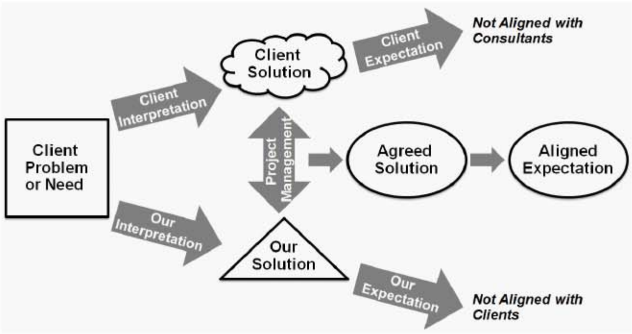

Figure 1 Using the proper application of project management processes, solutions are agreed on before their implementation in order to align the end expectations, otherwise different solutions would lead to diverging expectations.

Before proceeding to the implementation stage, it is important that project team members are on the same page as stakeholders by agreeing to a solution that is in line with the project objectives and goals, and the initial underlying need or problem (Figure 1). The proper application of various project management processes and through the continuous engagement of stakeholders, ideas are created, and alternative options are explored and investigated. The expected outcome of the project is defined once there is consensus on the solution. This is a critical milestone in managing expectations. The process of moving from having diverse opinions with several solutions to converging those opinions into a single agreed-upon solution requires the application of various project management techniques and skills.

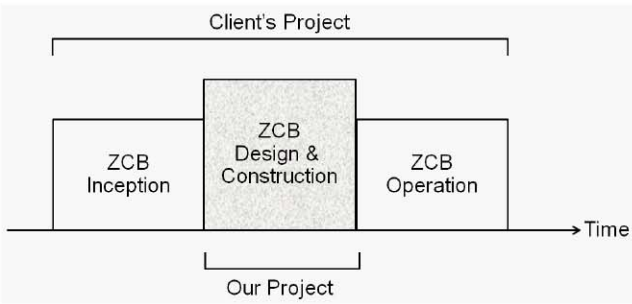

Figure 2 Our project is always just a component of our client's project. We always look at our project from a wider perspective and scenario.

In managing this process and their team, project managers need to consider the wider project aims of the client. The project scope provided by a client is usually just one component of a bigger project for their organisation (Figure 2). The objectives and goals of our project management team must ultimately align with the goals and objectives of the client's overarching project. Therefore the project must be viewed from a wider perspective and scenario. The project we are commissioned to complete is never a standalone project.

ZCB – The Project Background

According to government statistics, buildings in Hong Kong are responsible for approximately 60% of the total greenhouse gases (GHG) emissions in the city. In response to the Hong Kong Special Administrative Region Government (HKSAR)'s initiative to reduce overall GHG emissions, and as a landmark project in the Energizing Kowloon East Master Plan, the Construction Industry Council (CIC) in collaboration with the government developed the ZCB.

The CIC had a vision and enthusiasm for the project was obvious – the ZCB project would be the first of its kind in Hong Kong with state-of-the-art technologies. The ZCB would serve as a platform to share the latest zero carbon knowledge among the construction industry and would also function as an education centre to raise community awareness towards low carbon living.

The feasibility design commenced in April 2011 and the construction of the ZCB was completed in June 2012. ZCB was designed to attract more than 40,000 visitors a year. Guided tours are provided to explain the building design and demonstrate to visitors the various green features and technologies with a number of interactive exhibits.

Stakeholders Engagement

Project Governance

A fundamental aspect of project management was having a clear and defined governance structure. With the support of the government and professional institutions, under the instruction of CIC's Council, a dedicated task force that comprised of green specialists, architects, engineers, and other stakeholders of the construction industry, was set up at the inception stage to steer and oversee project delivery until construction completion. Similar to the function of the board of directors in a company, the task force was the party that the whole project team reported to, and where decisions were sought.

At the beginning of the project, the exact details and strategies of achieving zero carbon status, including how ZCB would compare to its counterparts in the world and its role in the city, were yet to be decided. To encourage the public to express their ideas and vision regarding zero carbon, a public forum called the "Zero Carbon Building Design and Technology Forum" was organised in April 2011 to ensure the public was engaged, its views gathered regarding the design process. The valuable contributions of different parties meant that the designers' approaches and strategies incorporated information from a series of discussions and investigations about various zero carbon buildings around the world.

The above process was never a simple, easy task, but it laid a solid foundation for managing expectations from the initial stage. Stakeholder involvement and consultation was vital to the decision making process.

Management Contracting

Just as in any other milestone project, once the project team was on board, there were hundreds of ongoing issues that demanded attention. This project was of especial urgency given that scientists were calling for immediate action to combat climate change. The design team was appointed on 17 April 2011 and commenced a feasibility study to investigate design approaches to achieve a zero carbon target. The exact schedule of accommodation was not yet finalised with the client. Given the tight completion date by early 2013, everybody was anxious to start construction works on site as early as possible. On the other hand, the site was scheduled to be ready for possession by the contractor in June 2011. Different forms of procurement for contractors were explored to discover if this would provide any programme benefit. There was consensus among the project team that other forms of construction contracts would be required, although a traditional design and build method would be the easiest and simplest methodology.

The project team was looking for a construction contract that could allow for design development in parallel with the procurement of contractors and construction on site. Among the various types of contracts, the options were subsequently narrowed down to management contracting and alliancing. A consideration of the project team's knowledge of construction contracts, and the availability of capable contractors, management contracting was finally adopted.

Then it came to the question: Who would be the contractual parties? The answer was simple for a management contract: the contractual parties included the client and the management contractor, with the architect as the contract administrator, and support from a quantity surveyor.

For the works contracts, either the management contractor or the client would sign the contract. Deciding between them involved a long debate among the task force members. The task force members grappled with a number of key questions including:

- Who would be the contract administrator in the works contracts? the project manager, architect or the management contractor?
- Which option had better protection for the client's right in contractor selection?
- Which option could better protect the client's interest if one contractor was not performing?
- Which option could better manage the works contractors?

As the management contractor could have better authority and management power over the works contractors, and the CIC did not have the resources to deal with so many construction contracts, the final outcome was eleven work contracts, supervised by the management contractor with the architect as the contractor administrator as shown in Figure 3.

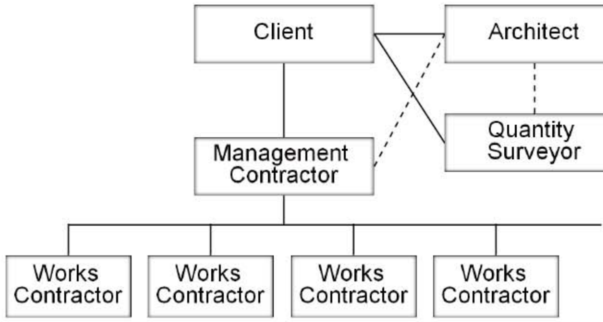

Figure 3 There were 11 works contracts managed by the management contractor with the architect as the contract administrator.

Key:
—— contractual relationship
······ administrative relationship

An added benefit of smaller contract packages was to allow small contractors to participate in the project to spread the knowledge they have acquired among the industry. This was entirely in line with the goals and objectives of the ZCB project. Stakeholder engagement and participation in the project was then extended to another level of the industry and helped to promote zero carbon targets.

Exhibition Content

Unlike other construction work contracts that had a defined scope of physical work once the building design was completed, the exhibits work contracts were – to a certain extent – similar to a design and build contract. At the time of the funding application, the theme and content of the exhibition was not determined, nor were there any quantitative descriptions of the exhibits. The budget estimate was totally based on the experience of the exhibition content designer.

After several months of discussions with the exhibition panel, the design was approved to be in the format of a guided tour. It was decided that the exhibition route would be a journey that took people from "why, what, how much and how." It offered a 3D movie as an introduction, followed by various exhibits in the eco-office, and then three interactive displays on the mezzanine floor. An eco-home would illustrate the theme of low carbon living. Then, the tour would cover the basement level to explain the mechanical and electrical systems at work in the building. Scattered along the ring path in the landscape area, ten display nodes were designed to explain the concept of 'One Planet Living'. The works involved film production, graphic design, interactive exhibits production, and carpentry work.

The expected final quality of the contract was driven by the approved budget from the client. In other words, the client agreed to buy a car. There were different qualities to choose from: it could be a Rolls Royce, a Mercedes-Benz or a Toyota. All these models would fulfil the same basic function but the quality expectation of the end product would be totally different.

With a cap on the contract costs, the budget was inserted into the tender document. Tenderers were required to work within the budget by proposing suitable audio visual systems, related production works, and presentation format – all as long as the theme, that is the approach to performance specification, was followed.

The process not only controlled the project costs but also managed the expectations. Using simple language and relating the deliverables with objects that everyone could easily imagine was a critical factor to ensure that all stakeholders had the same understanding. Getting all the team members on the same page, and ensuring the right messages were shared with the different stakeholders, were essential to managing appropriate expectations. One golden rule in managing a communications process among a broad audience is to avoid jargon and specialist languages.

Conclusion

The topic of climate change is no longer new, but the Hong Kong government's response of adopting a zero carbon building project is relatively new to the local construction industry. There is still no single internationally recognised and consistent definition of what makes a zero carbon building.

At the beginning of the project, the project team was not clear on the technical approach to achieve the long-term goal of zero carbon. As a result, the expectations of different people varied significantly. It was only through the process of stakeholder engagement and involvement during project implementation, that project objectives and goals were reexamined, and tested with alternative options before a consensus was reached on a final solution. This process was a key driver of the project's success.

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Marian Kwok, a Senior Project Manager of AECOM Asia Co Ltd, is a Project Management Professional, Registered Architect and Authorised Person (Architect) with over 14 years experience in project management and architectural practice. Before joining AECOM in 2010, Marian practiced as an architect taking up architectural planning, design and contract administration positions.

606 polycrystalline photovoltaic panels used on the main roof

On-Site Renewable Energy generation at the ZCB

A major goal for the ZCB is to have 100 percent of the building's energy supplied by on-site renewable energy generation. The main source of energy generation for the ZCB is through a biofuel tri-generation system utilising waste cooking oil (Grade B100)—estimated to produce 143MWh/yr. Coupled with this is the use of solar power estimated to produce 87MWh/yr.

Three different types of photovoltaics (PV) at three different locations are used: (1) Polycrystalline PV on the main roof (606 panels at an incline of 17 degrees-20 degrees); (2) Building Integrated PV on the glass roof of the viewing platform; (3) Cylindrical CIGS used at the Eco-Cafe. Together, renewable energy generation would exceed anticipated energy demand estimated at 100MWh/yr.

Building Integrated Photovoltaics (BIPV) used as glass roof of the viewing platform

Cylindrical Copper Indium Gallium, Selenide (CIGS) collectors absorb direct, diffused and reflected sunlight from 360 degrees

Adsorption chiller driven by recovered heat of the biofuel generator

Biofuel tri-generation system uses waste cooking oil for cooling, heat production and power generation

LOW CARBON CONSTRUCTION

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Summary

The ZCB is a signature project designed to raise the community's awareness about sustainable living in Hong Kong. The ZCB is a two storey building with a basement that accommodates the plant rooms. The landscaping area consists of hard and soft landscape and a native urban forest with a covered walkway, water features and multi-function areas. The building will provide an opportunity for the public to see and experience the most advanced green designs and technologies for promoting a low carbon lifestyle. The Construction Industry Council (CIC) selected Gammon Construction Ltd. as the management contractor for the project because of its expertise in green construction technologies and practices.

Several low carbon construction initiatives were implemented during the construction of this iconic building in Kowloon Bay. A full scale carbon accounting system was implemented to record the carbon emissions associated with the construction process and also the embodied carbon within the major building materials. Building Information Modelling (BIM) was used during the construction phase to accurately predict the cut and fill quantity to reduce the transportation of inert waste to public landfills. Gammon's concrete department produced specific concrete mixes with recycled aggregates to further reduce the building's carbon footprint. Gammon also used its procurement department to aid the work contractors in obtaining sufficient amounts of steel manufactured with recycled materials.

Keywords

zero carbon building, low carbon construction, carbon accounting, construction management, green procurement, green building

Introduction

The CIC collaborated with the Hong Kong government to develop the first Zero Carbon Building in Hong Kong with the twin goals of showcasing cutting edge green building technology and to stimulate Hong Kong's local green building development. As a leader in green construction and planning, Gammon Construction Ltd. had proposed and successfully implemented several programmes and service packages, to facilitate the project prerequisite of low carbon construction.

Carbon accounting, the supply of concrete with recycled aggregates, BIM on backfilling estimations and sourcing sustainable materials were the highlights of Gammon's strategies to pursue low carbon construction. With the immense support provided by Gammon's various departments and staff, the company successfully completed the project and achieved outstanding results from its low carbon construction strategies.

Project Carbon Accounting

One of the stipulations of ZCB was to account for its carbon emissions during the operational stage, as well as the embodied carbon present during the construction process, and in major structural materials. In line with these requisites, Gammon developed a carbon monitoring programme to monitor and record the carbon emissions from various construction activities. These included on-site machinery fuel consumption as well as the embodied carbon of major building materials.

Three scopes for carbon emission accounting during the construction process were defined according to the Greenhouse Gas (GHG) Accounting Protocol:

- Scope 1 All Direct GHG emission: combustion of fuels on site;
- Scope 2 Indirect GHG emission: consumption of purchased Energy;
- Scope 3 Other indirect emissions: transport-related activities in vehicles not owned or controlled (such as transport of purchased concrete to site).

Figures 1, 2 and 3 illustrate the types of emissions accounted for in the project.

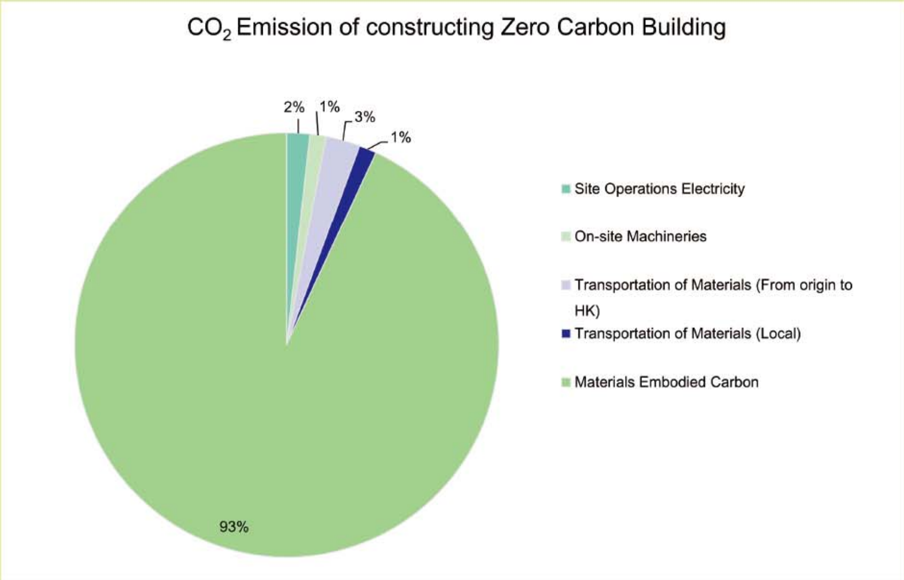

Figure 1 Carbon accounting for construction processes

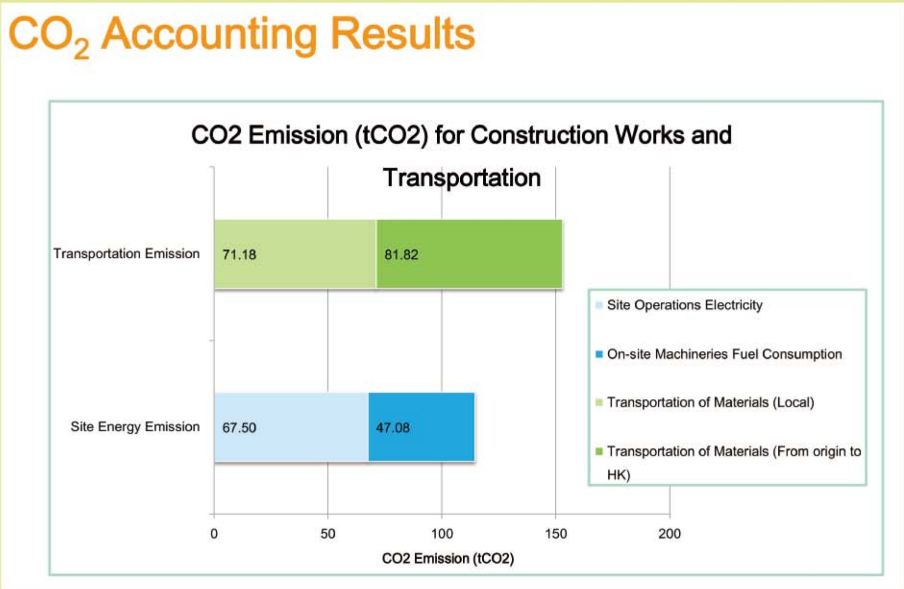

Figure 2 Comparison between carbon emission from site construction process and materials transportation

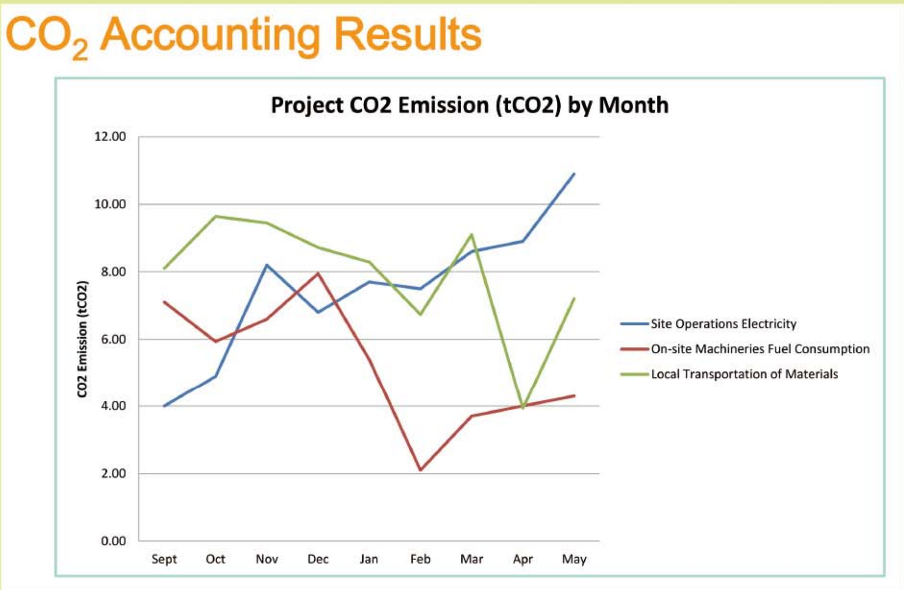

Figure 3 Project carbon emission by month

The key to implementing the carbon monitoring programme was to understand, assess and facilitate any carbon reduction strategies for the project, or any strategies that were already used as case studies in building lifecycle analysis.

With comprehensive data collected from the carbon monitoring programme, the carbon hotspots were successfully identified. The embodied carbon of materials made up more than 90% of carbon emissions during the construction stages. The transportation of materials, on the other hand, contributed a small amount of carbon emissions. However, the measurement of these emissions required significant effort in terms of data collection. A reduction of carbon emissions from on-site machinery was a result of reduced fuel consumption once the earth works were completed. The increase in project electricity consumption near the end of project was the result of increased labour and tools used and from undergoing testing and trial runs for the building systems. Through an understanding of the carbon emissions associated with various site activities, Gammon was able to then identify carbon intensive construction activities and seek sustainable strategies to pursue low carbon construction.

Cut Soil Schedule	
Mark	**Volume**
1	1063.10 m³
2	152.34 m³
3	5879.60 m³
4	3502.26 m³
5	146.22 m³
6	51.22 m³
7	16.80 m³
8	13.17 m³
9	8.63 m³
10	17.36 m³
11	22.03 m³
12	0.17 m³
	10872.90 m³

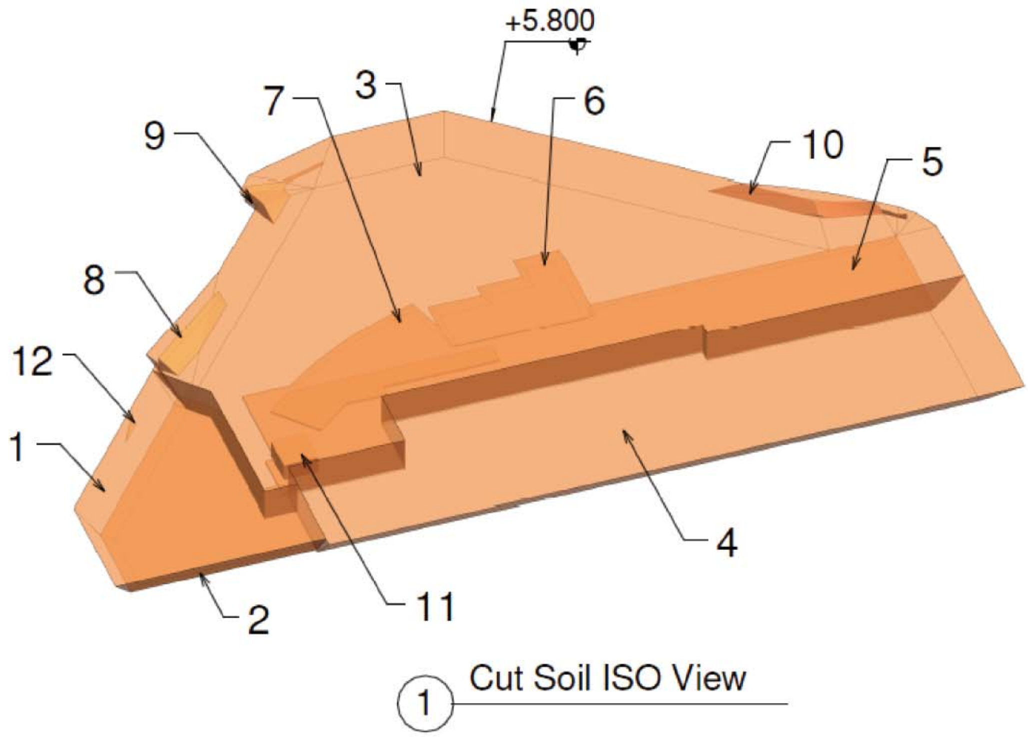

Figure 4 BIM technologies to project accurate excavation quantity

Back Fill Schedule	
Mark	**Volume**
1	337.59 m³
2	15.90 m³
3	446.84 m³
4	560.77 m³
5	0.84 m³
6	309.29 m³
7	97.75 m³
8	315.72 m³
9	19.59 m³
10	444.67 m³
11	78.57 m³
	2627.54 m³

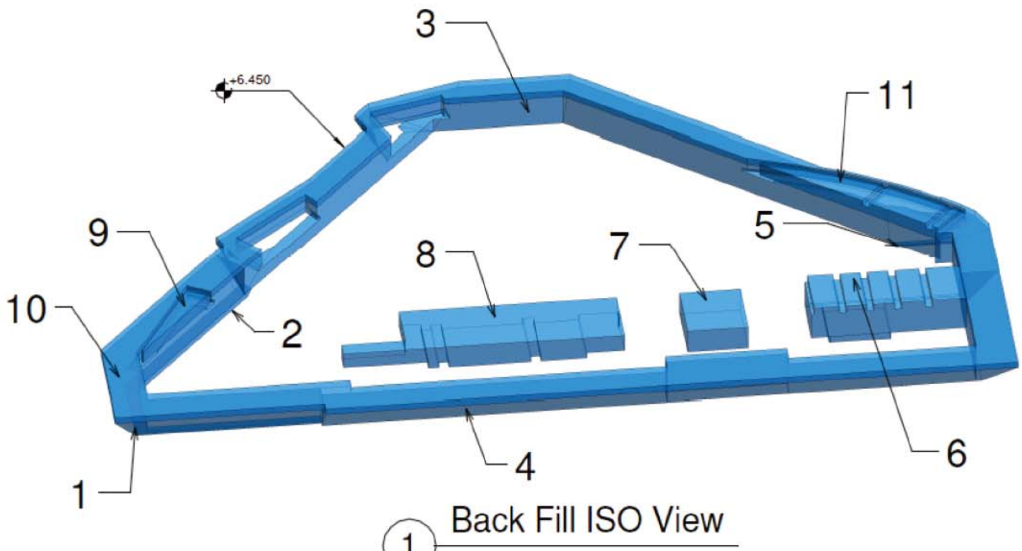

Figure 5 BIM technologies to project accurate filling quantity

Implementation of BIM for Cut and Fill

BIM technology was used in the ZCB project to control the excavation process with the aim of avoiding the unnecessary transportation of excess cut and fill materials. BIM was used to estimate the cut and fill quantity according to the building programme, and as a result, it minimised the need to cart away ground soil that would later require backfilling (Figure 4 and Figure 5). Accurate BIM projections facilitated smooth site logistics and helped reduce the carbon emissions from excess transport truck use.

Supplying Recycled-Aggregate Concrete

In order to increase the recycling content to reduce the carbon footprint, the project specifications requested recycled aggregates to produce blinding/low-grade structure concrete (Grade 35 or below). In the Practice Note from Building Department and the General Specification of Building from Architectural Services Department, "Recycled Coarse Aggregates" is defined as the material produced by crushing old concrete. However, such recycled coarse aggregates were not available in the local market. To further complicate the issue, the manufacturing cost for recycled aggregates was extremely high because of the limited demand from projects like ZCB. Therefore no concrete manufacturers were able to provide the specified concrete.

Despite the above limitations, Gammon's concrete department was able to provide valuable assistance in supplying the prescribed concrete mixes. A concrete reclaim system was established to handle the residue concrete waste returned from the site and separate the coarse and fine aggregates from the cement slurry and reduce the final dumping volume wastage to landfill. After conducting a series of physical and chemical tests on the reclaimed aggregates, the properties of the coarse aggregates complied with the relevant standards and specifications. The ZCB project was the first project in Hong Kong to use recycled aggregates extracted from surplus concrete for the production of new low-grade structural concrete. Figure 6 and Figure 7 below illustrate this process and the embodied carbon of concrete mixes.

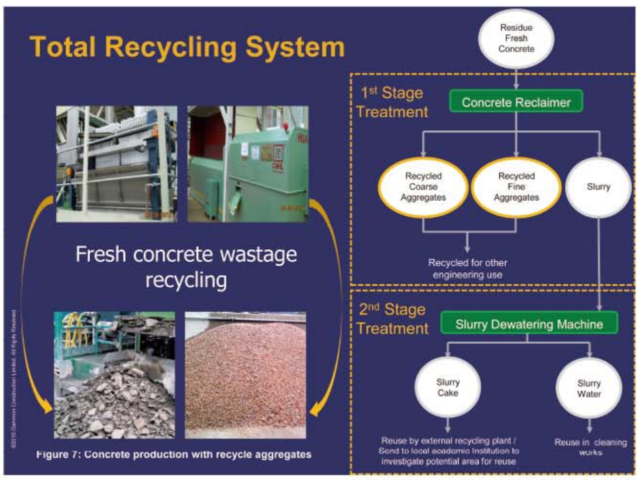

Figure 6 Concrete production with recycled aggregates

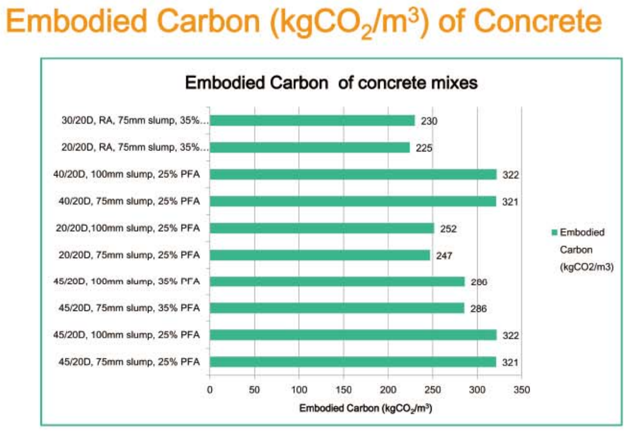

Figure 7 Concrete production with recycled aggregates

Sustainable Procurement

In its goal to become the most sustainable building in Hong Kong and attain the Platinum level of Hong Kong BEAM Plus green building certification, the ZCB project maximized the use of building materials with recycled content and sourced regionally manufactured products. Gammon procurement took a leading role in sourcing materials and helped works contractors to find local/regional materials as well as materials with recycled content. Gammon's procurement department also helped its associated contractors purchase sustainable wood products and rebar that had a high recycled content.

Conclusion

Gammon's efforts to deliver this green project went far beyond common day-to-day site coordination. Gammon implemented a comprehensive carbon monitoring programme to identify carbon hotspots and gathered solid data for carbon offsetting.

Gammon also assisted the project team in supplying a concrete mix with recycled aggregates and pulverised fly ash to promote the use of green materials. With its in-depth connection to the material supply side, Gammon influenced and assisted various works contractors to source green materials, such as rebar containing recycled contents, and timber products from sustainable sources.

BIM technologies were used to project and estimate the cut and fill quantity according to the building programme, thereby minimising the need to cart away ground soil that would later need to be backfilled. As a leader in green construction and planning, Gammon assisted the client to meet the stringent requirements for low carbon construction, and significantly contributed to the green building movement in Hong Kong.

Mr Woo, Man King is the Executive Director of Gammon Construction Limited. He graduated from the Hong Kong Polytechnic University in the course Building Technology and Management. He owns Corporate Membership of the Hong Kong Institute of Surveyors, Chartered Institute of Building and Hong Kong Institute of Construction Managers. He has over thirty years of working experience in the Hong Kong building industry.

He is now the Technical Advisor (Construction Division) of the Hong Kong Employees Retraining Board, and a Committee Member of the Building Committee of the Hong Kong Contractors Association. He was appointed a Committee Member of the Building and Civil Engineering Training Broad of the Hong Kong Vocational Training Council in 2007-2013.

Climbers on wire ropes

Climbers on walls

Climbers supported by wire mesh training system

Landscape at the ZCB

ZCB aims to be climate-positive. Greenery coverage close to 50 percent of the site with some 399 trees helps to alleviate the urban heat island effect in a dense urban environment such as Hong Kong by lowering the Local air temperature.

Based on ecological concepts, ZCB features an urban nature woodland - the first of its kind in Hong Kong. Environmental benefits include enhancing biodiversity, cooling, removal of gaseous and particulate air pollutants, noise abatement and groundwater treatment. Diverse native tree species, shrubs, turf and vertical greening act as heat and carbon sinks (each mature tree is estimated to absorb 23kg of CO_2 per year) whilst offering visual amenity for the local community. Native species also require less water use.

High greenery coverage removes carbon dioxide and gaseous and particulate air pollutants

Hong Kong first Urban Native Woodland

Diversity of species offer visual amenity

LANDSCAPE DESIGN STRATEGIES DEVELOPED FOR THE ZERO CARBON BUILDING AND PARK PROJECT

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Summary

The 14,700 m² site, allocated by the Hong Kong government to the Zero Carbon Building and Park Project (the ZCB Project), was zoned for Open Space Uses under the Outline Zoning Plan S/K13/26. The ZCB Project is consistent with previous planning intentions for this site in that, whilst open space is the predominant use, functions and developments permitted under the land-use zoning's Column 1 Uses included: Parks, Gardens, and Pavilions, as well as ancillary uses, such as Field Study, Education and Visitor Centres – of which the ZCB is an example.

The Open Space zoning earmarks the site, which had earlier been occupied by the Sheung Yuet Road 'Construction Industry Council' Training Ground, for development as a District Open Space for enjoyment by the Local Community.

Figure 1
Zero Carbon Project on completion in June 2012

Figure 2
Urban Forest Walks

Figure 3
Retained Mature Trees

Figure 4
Landscape Masterplan

A District Open Space, in this location, should provide recreational facilities and amenity areas; should become a 'green' refuge from the adjoining urban streetscapes; should contribute to the 'greening' of surrounding streetscapes; should provide an attractive 'green' prospect for adjoining developments; should secure the passage of ventilating breezes across the District; and should seek to introduce nature to the City. The Open Space should also be a memorable space, which provides the District with a visual and spatial focus, and should become a local landmark which provides the District with a significant point of orientation. It should provide an attractive environment for formal and informal public activity, and be a public space which enhances the character, identity and vitality of the District.

Permitted ancillary uses, under the provisions of the Outline Zoning Plan are intended to provide an opportunity for enhancing the function, use and attraction of the District Open Space.

The precise nature of these ancillary uses and their role and level of presence in District Open Spaces can vary greatly from open space to open space, but they often play a significant role in defining the intrinsic character of those open spaces. This is particularly true with regard to the ancillary uses in the ZCB Project, as the very specific nature, character and intention of the Zero Carbon Building, which is the focus of the Project, is not only expressed in the fabric and exhibition content of the Building, but is also expressed in the Building's siting and form within the Park (its context), its integration with the Park, and in the complementary design of the Park.

The Zero Carbon Building and Park, demonstrate in their fabric, content, layout, planning, and construction techniques the potential role and application of sustainable design in all development projects. Whilst the park is to be an open space resource for the community, it is in this sense, as much a demonstration project as the ZCB is of sustainable design practice.

Figure 5
Eco Plaza:
- multi-functional events and exhibition space;
- natural timber decking from sustainably harvested forests.

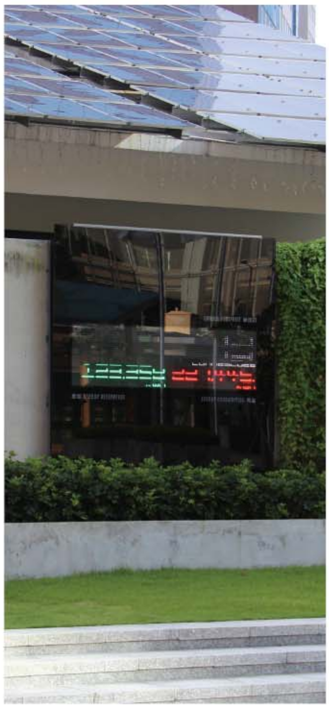
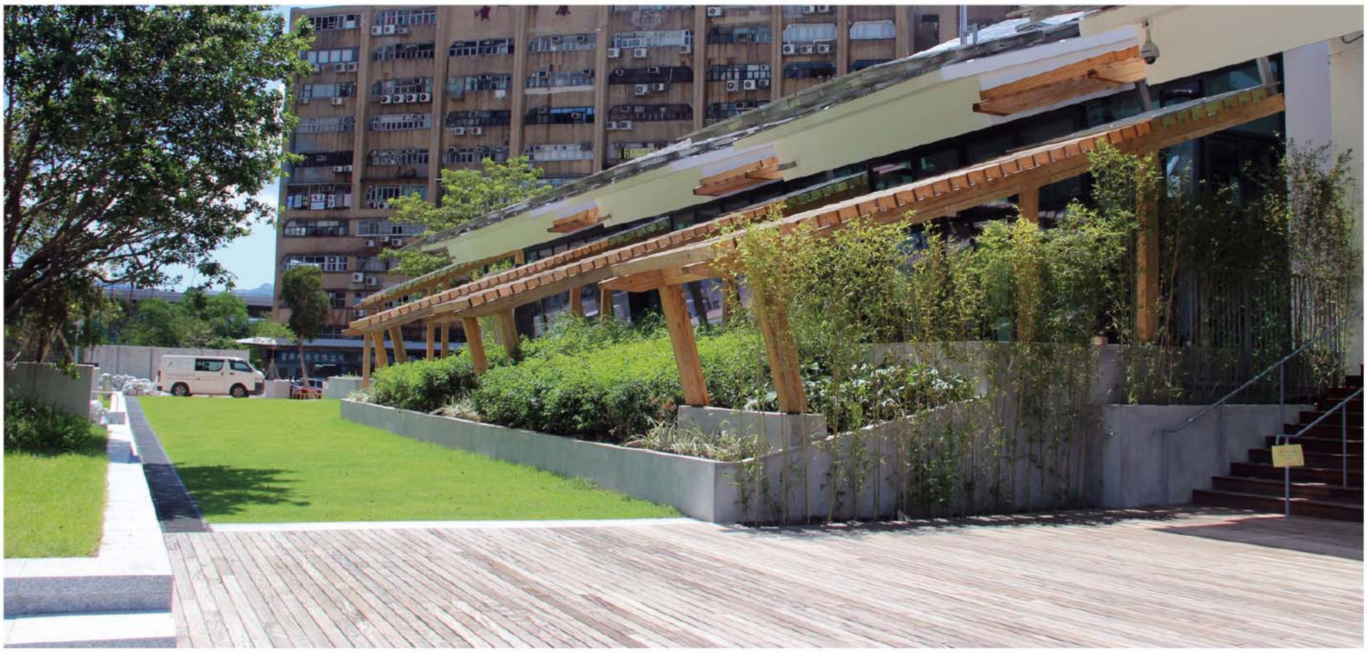


Figure 6
Real-time monitoring of energy generation and consumption within the Zero Carbon Site

The integration of building and park, in terms of design philosophy and approach, has been a feature of the project since the very first concept design strategies were produced. These strategies remained largely unchanged throughout the detailed design development and construction stages of the project. Whilst the layout, form and integration of the Building and Park is in many ways a response to the environmental context and the principles of sustainable design, this project, like most others, also has to work within the parameters placed on its design by contextual design constraints. It needs to achieve sustainable design objectives within the framework of such constraints.

Significant contextual elements and constraints which have heavily influenced the evolution and nature of the design solutions for this site and development comprise of, the adverse visual, physical and auditory impacts of adjoining streetscapes; the significant visual presence of adjacent tall developments; the circumscribing form of adjacent tall developments, which cast shadows across the site and influence the pattern and direction of breezeways; site levels and the lack of a varied topography; the location of vehicular access points, pedestrian access points and pedestrian desire-lines across the site; and the sterilisation of large areas of the site for development, and the placing of significant localised restrictions on permissible landscape strategies as a result of the underlying presence of large stormwater culverts, which cross the centre of the site in a north-east to south-west direction and occupy a significant proportion of the site.



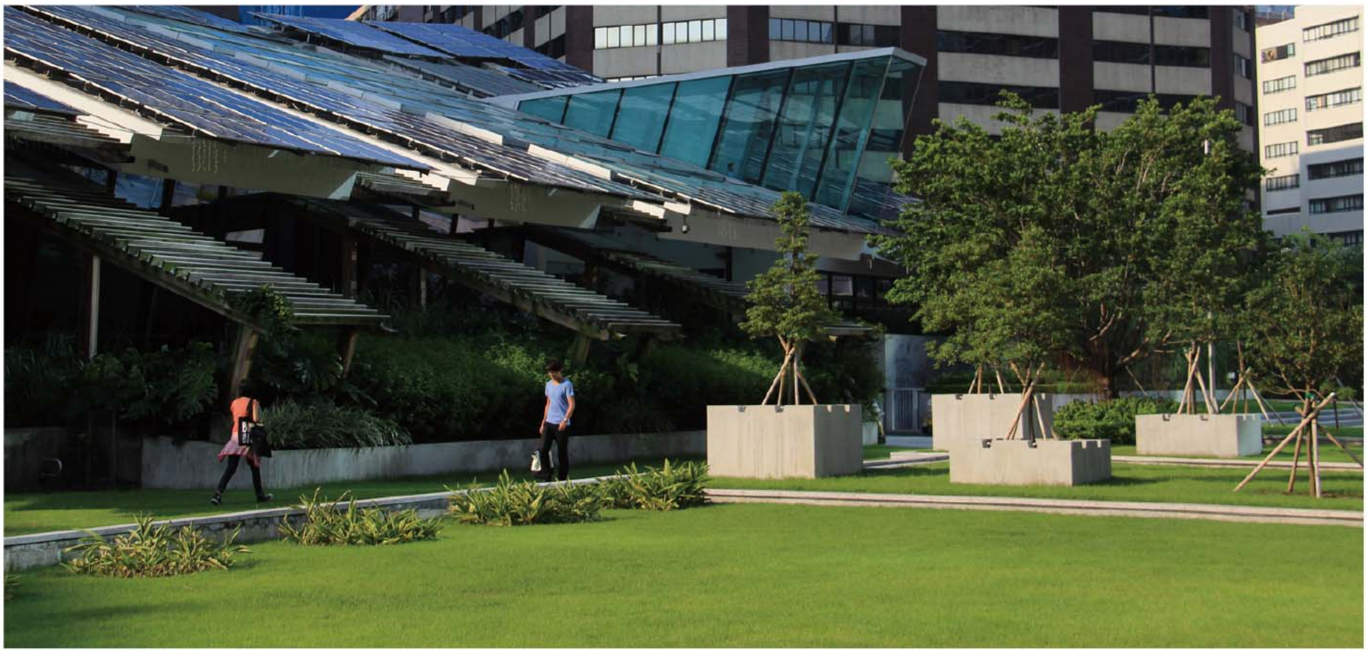


Figure 7 & Figure 8

Integrated architectural forms and landscape treatments designed to merge the building and the landscape:

- use of pergolas and green roofs to extend ground level landscapes onto the roof of the building;
- use of reinforced grass finish in areas requiring vehicular access to enhance ground permeability and to optimise greening.

The physical and visual integration of Building and Site is achieved by integrating the Building within a quadrant of a large circular walk – the 'Zero Carbon Walk' which visually and physically unifies the various parts of the site; which visually circumscribes the 'heart' of the site (the Eco Plaza and the Eco Terrace's Great Lawn); and which is the primary connector of interior exhibition and demonstration spaces within the Building to similar spaces set within the adjoining Park. The circular walk provides an easily cognisable and legible circulatory framework for the site and an organisational framework for the siting of building elements, major event and exhibition spaces, smaller demonstration and exhibition spaces and passive recreation spaces.

The physical integration of the Building and Park not only considers the appropriate placement of the Building within the Park Layout, i.e. the 'figure and ground' composition of the development, but the total immersion of the Building within the 3-dimensional composition of the Park. Whilst the Building is intended to have a distinct character and identity in its own right, it is also designed to reinforce, in the third dimension, the arc of the circular walk; to dynamically emerge out of the ground-plane of the Park; and to accommodate the visual and physical extension of the Park across its roof, from 'green finger' extensions of planting within the Park to planted pergolas and green roofs sweeping upwards from the Park, onto and across the Building's roof-scape.

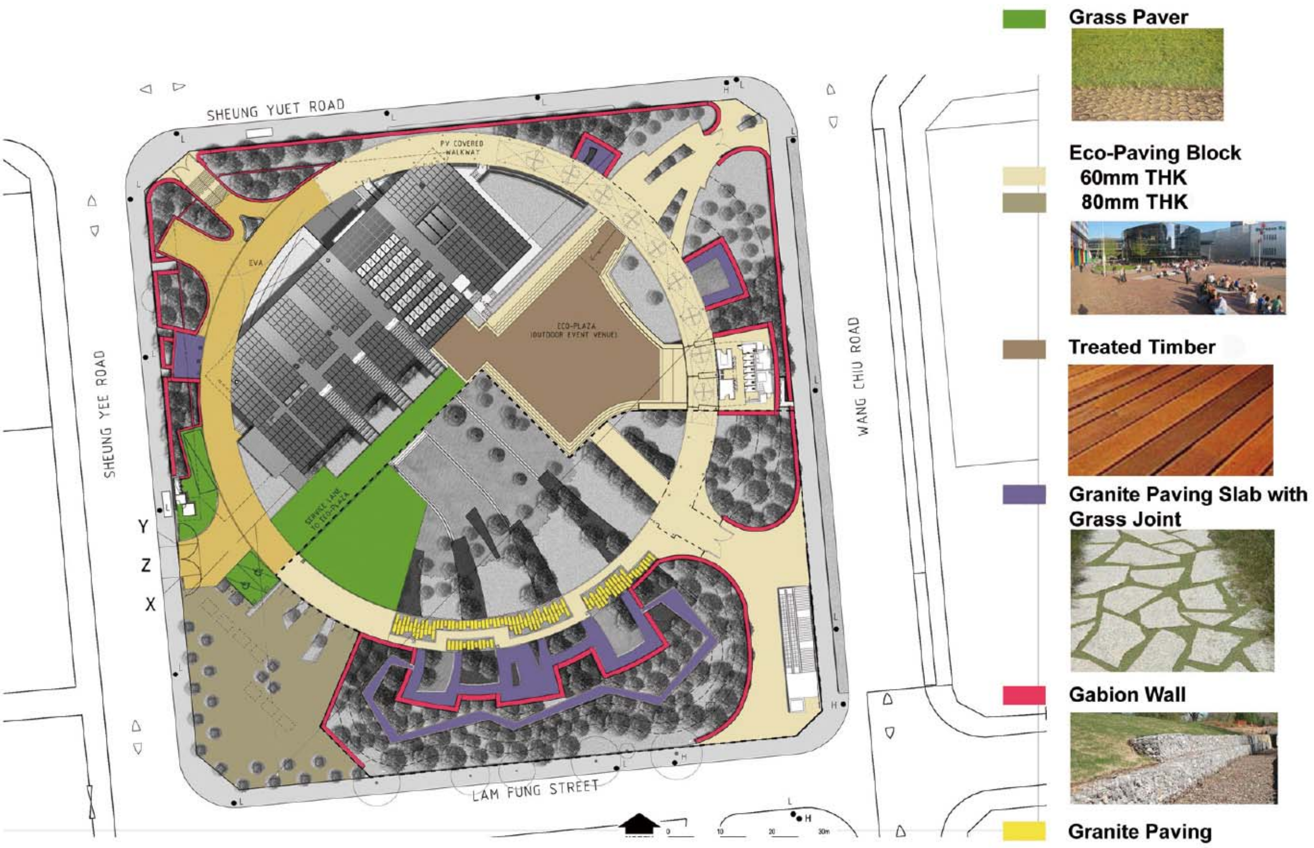


Figure 9
Materials and Finishes Concept

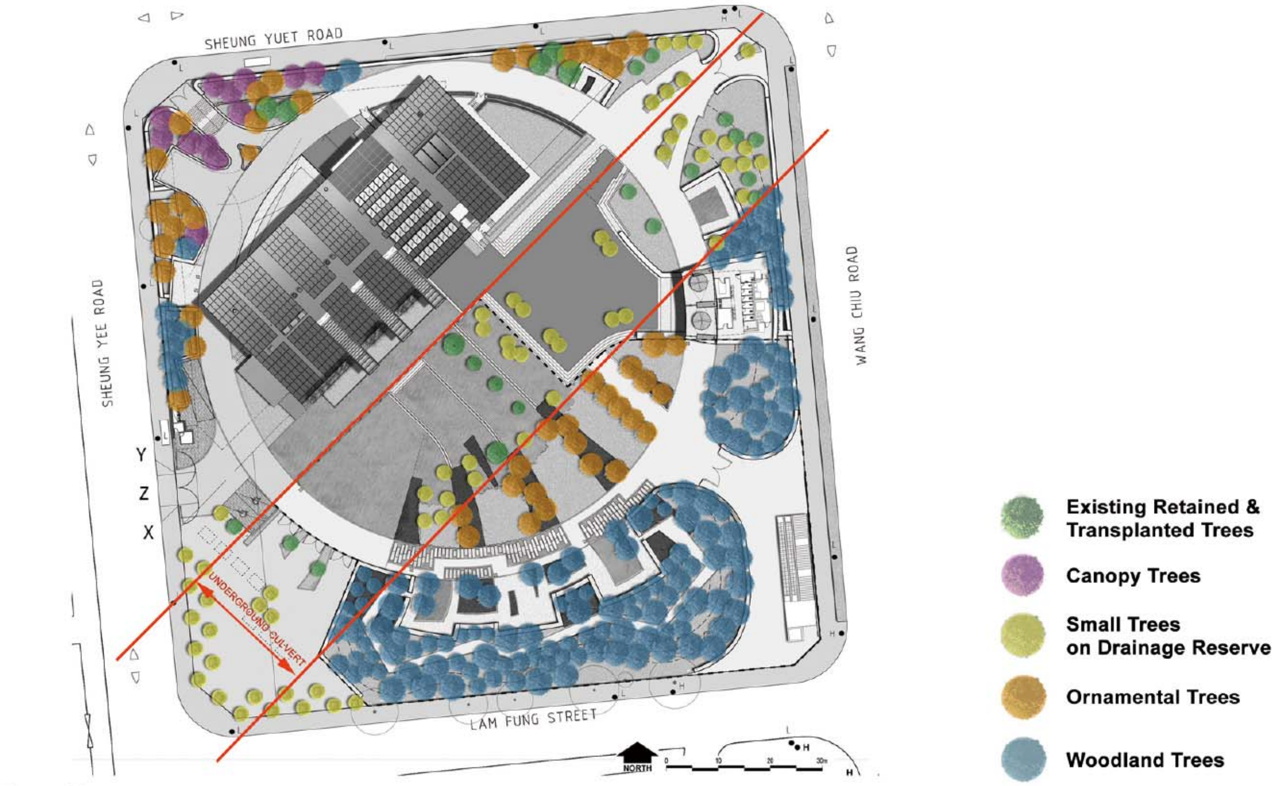


Figure 10
Tree Planting Concept

Another feature of the Project is the integration of a dense belt of tree and shrub planting along the perimeter of the site. This belt physically and visually defines the central exhibition and event spaces; adds significant greening to the streets; provides a visual and physical screen between the central exhibition and event spaces and the surrounding urban streetscapes, and thereby assists in the development of the Park as a 'green' recreational refuge space from the surrounding busy urban areas.

Summary of Landscape Features and Approaches

Landscape Features

- the 'Zero Carbon Walk' – a circular pedestrian spine, providing access to all areas of the site;
- the 'Urban Forest' – an area of engineered Native Woodland along the southern and eastern edges of the site;
- the 'Eco Plaza' – a large area for outdoor exhibitions and events;
- the 'Eco Café' – a facility for park-users and events in the Eco Plaza;
- the 'Eco Terrace' – a grand, terraced lawn for formal and informal exhibitions, events and recreation, forming a direct extension of the Eco Plaza; and,
- the 'Eco Hives' – small-scale exhibition, gathering and display alcoves set within the Park.

Figure 11
Retention of construction site-hoarding foundations as a feature of the finished retaining wall

Figure 12
Removable tree planters located above pre-existing drainage culverts

Figure 13
'Air-Tree' Pergola:
- provides shade;
- provides local cooling.

Landscape Approaches

Landscape designs incorporate recycled materials, renewable materials, locally sourced materials, low energy input materials, and materials sourced from sustainable sources. Designs avoid materials, products, and practices that are harmful to the environment.

Construction activities use methods and practices that minimise waste, pollution and the degradation of the environment.

Demolition waste from the demolition of structures on the site, and construction waste associated with construction activities are used, as far as practicable, in the construction of landscapes and landscape features. This include:

- the use of construction and demolition waste generated by the site to significantly modify the topography of the park, to circumscribe discrete spaces, to create platforms, to introduce level changes and gradients, and to create landscaped berms around the perimeter of the site;
- the recycling of concrete slabs from demolition works to create fill material for gabion retaining walls, and to provide sub-base material for areas of paving; and
- the retention, as part of the finished design, of concrete blocks and foundation pads used to support temporary construction hoarding, along some sections of the site's perimeter.

Grey water and stormwater is collected, treated and re-used for landscape irrigation using intelligent irrigation systems linked with weather monitoring systems. Stormwater is also collected and used in an engineered wetland, and is used to demonstrate the principles of systems that can be introduced to new construction projects to partially treat collected grey water or stormwater using plant material as part of the water treatment process.

In the interest of minimising water consumption requirements, selected plant species are both native species and a range of species commonly found in Hong Kong landscapes. All plants are appropriately adapted to Hong Kong's environment and climate, can tolerate dry conditions, and/or have low water consumption requirements.

Landscape materials include paving made from recycled materials, laid to provide a porous surface that will allow ground waters to be recharged by stormwater, and whose material composition has an ability to remove pollutants from the air; reinforced grass surfaces and grass-crete paving used to provide porous 'green' surfaces suitable for vehicular loading; treated timber and timber decking which has been sustainably harvested and is certified by the Forest Stewardship Council (FSC) or the American Forest and Paper Association (which promotes responsible forest management); and recycled timber products, recycled concrete and recycled masonry.

Local granite is used as a fine finish paving material, where considered appropriate, such as in exhibition alcoves, as special feature paving on the circular walk, as wall cladding and step finishing and edging, and as a facing material for rubble walls. Local granite was selected as it is readily available, visually expresses the regional character of the development, and contributes to the development of a specific sense of place.

Figure 14
Demonstration Green Wall Systems:
- to enhance greening coverage;
- to reduce heat island effects.

Figure 15
Zero Carbon Walk comprising:
- grassed areas and grassed joints in local granite paving;
- recycled glass aggregate paving with air-borne pollutant removal properties;
- stormwater permeable surfaces and joints to re-charge ground waters.

Pre-existing trees have been retained or relocated. Great care was taken in the construction of landscapes in close proximity to the rooting systems of existing mature street trees within adjoining public pavements, in order to minimise adverse impacts on the health and stability of those trees.

The greening of the site, in the form of horizontal greening, vertical greening, and roof greening equates to 49% of the total site area. Greening significantly contributes to the reduction of local carbon dioxide levels by acting as a carbon sink.

A largely continuous green threshold is provided around the perimeter of the site using densely planted trees and under-storey plants and shrubs. These enhance the greening of the street, screen streets from the central area of the park, and create a green refuge for pedestrians from adjoining urban streets.

A wide variety of tree and shrub species, representative of species commonly found within Hong Kong's urban landscapes, are integrated along the northern and western edges of the site, and a unique urban woodland (the Urban Forest) is provided along the southern and eastern edges of the site as a demonstration project of the potential for native woodlands to be introduced into the inner-urban areas.

The selection of materials, the optimisation of 'greening', the use of shading devices and the retention of breezeways seek to address the need to minimise the Heat Island Effect of the Building and Park, and in so doing, reverse or at least reduce the significantly more extreme Heat Island Effect generated by the site in its original state.

Reversing/Reducing the Heat Island Effect Generated by the Original Site

The original site largely comprised a raised concrete covered construction training ground on which there were very few trees and very few areas of planting. The performance of the ZCB in reducing the Heat Island Effect of the site is thereby significant.

Figure 16
Pre-Zero Carbon Building Project site in May 2011

Figure 17
Post-Zero Carbon Building Project on completion in June 2012

The Minimisation of the Heat Island Effect of the Proposed Project

The Heat Island Effect is minimised principally through:

- optimising the greening of horizontal surfaces and roofs, the vertical greening of structures and facades, and the use of grass-crete and reinforced grass surfaces for occasional vehicle traffic;
- the use of light coloured hard landscape finishes;
- the shading of hard surfaces with sections of the building, eaves and shade canopies;
- the integration of a large number of trees, whose canopies will, in the medium- to long-term, provide paved surfaces with additional shading;
- facilitating air-flow across the site by retaining natural breezeways and introducing elements which promote air movement and cooling such as the rotary fans in the Eco Café canopy.

The location of the ZCB and its orientation is designed to optimise the insolation of the roof-scape so that it can be effectively used as a solar energy collector, and to avoid restricting the passage of natural seasonal breezeways across the site, which serve to ventilate and cool the site and the adjoining urban street canyons.

More than 4,000 m^2 of paving uses light coloured pervious paving materials, which are laid to allow rainwater to percolate through the paving joints and re-charge the site's ground waters. Non-permeable paving is restricted to the Eco Plaza event space and to the emergency vehicle access routes along the north-western edge of the site. All paving materials have been selected to be light in colour in order to reflect sunlight, without causing excessive glare, and thereby assist in reducing the Heat Island Effect of the development.

Many areas of paving are shaded by canopy structures and the roof of the ZCB. Projecting eaves on the ZCB also serve to provide shading to external building facades, and the integration of vertical greening on building facades in many areas provides further shading to the facades.

In areas not occupied by solar energy collectors, green roofs are used on the ZCB to reduce the Heat Island Effect, and to extend the greening of the site over the building.

The retention of existing mature trees on site, and the development of landscapes which integrate high densities of new tree planting, will result in a significant increase in the shading of hard landscapes over time.

Figure 18 & Figure 19
Park route to the Eco Plaza and Zero Carbon Building

The total site area, including what is occupied by the footprint of the Zero Carbon Building, is 14,400 m^2. The total 'greening' across the site covers 49% of the total site area, of which 46% is horizontal greening on grade and roof surfaces, and 3% is vertical greening on the facades of the building and screen walls adjoining the building. Hard landscape surfaces have been minimised to areas required for regular vehicle access, emergency vehicle access, pedestrian circulation, and gathering spaces.

The site integrates 399 trees, of which:

- 151 trees comprising 53 non-native signature trees intermixed with 98 native trees, are largely located at gateways to the site, and along the northern and western edges of the site;
- 7 trees, which were originally found on site prior to the commencement of the ZCB Project are retained in their original location;

- 19 trees, which were originally found on site prior to the commencement of the ZCB Project, have been transplanted to new locations within the site;
- 222 native trees are integrated within the Urban Forest area along the southern and western edges of the site (an area which is adjoined, along the southern edge of the site, by 5 very large and mature banyan street trees, which provide a very significant visual backdrop to the Urban Woodland);

A significant constraint on the location, extent and nature of greening the site with trees, and the optimisation of the Project's biomass, is that of shallow stormwater culverts running beneath a significant part of the site from the north-east to the south-west corner of the site, and the related need to integrate access points for the regular inspection of the underlying culverts; to avoid substantial additional loading of the culverts; and to design over-sailing landscapes so that they can be relatively easily removed, should the culverts need to be excavated in future.

Trees above the culverts are relatively few and are planted in removable planters, so that trees can be relatively easily moved should the urgent excavation of the culvert be required. The principal landscape treatments for areas immediately above the culverts comprise of terraced lawns and shrub planting, and relatively fewer trees than are provided in the areas to the north and south of the culverts in real ground.

In some areas removable tree planters are buried below-grade, but in others, where the water table is high or where there are underlying culvert structures close to the surface, removable planters protrude from the face of the completed landscape. As this design strategy is a significant part of the story of how the Project has both sought to optimise greening and address the particular requirements of the context, removable planters and their lifting-eyes are not disguised or concealed, but are deliberately exposed as a feature, and the reason for their design and appearance made evident to visitors to the site.

The Urban Forest comprises an engineered urban woodland using native shrub and tree species, and makes a significant contribution to the biomass of the Project, and the minimisation of the Heat Island Effect of the Project.

Whilst the woodland is relatively small in area, the intention behind introducing it is not only to enhance the biomass of vegetation within the site and to fulfil functional, spatial and visual objectives, but also to bring a representation of nature into the City; to demonstrate how this can be achieved; to introduce to visitors, as wide a range of native woodland species as can be sourced from local nurseries (particularly flowering species); and to demonstrate the temporal nature of evolving landscapes in a city in which urban landscapes are largely designed for instant and unchanging effect.

The availability of a wide range of native tree species from commercial nurseries was found to be limited, both in number

Figure 20 & Figure 21
Gabion walls and retaining walls:
- use excavated concrete ground slabs as aggregate in gabions;
- use local granite rubble as a facing material to foster a local sense of place;
- use demolition waste to give the site a more varied topography.

Figure 22
Urban Forest Walks and Eco Hive Exhibition and Event Spaces

and maturity. This being the case, under-planting, comprising 10 native species (7,600 plants), plays a significant role in meeting project objectives until such time as the intended mass of greening is achieved upon the maturing of woodland trees, whips and seedlings. As trees mature and canopies spread, native shrub under-planting and grass cover will also adjust to changing light conditions. In this sense the Urban Woodland is seen very much as an evolving landscape, and the story of its development and evolution is intended to be of long-term educational interest.

Whilst native tree species can be found in many urban areas, it is rare that so many species can be seen in such a concentration, and in such a conveniently accessible location. Evergreen and deciduous trees, brightly coloured seedpods and flowers will provide an ever-changing display. 44 native tree species are represented in the 222 native trees planted within the Urban Woodland, ranging in size from seedlings and whips to heavy standards.

Conclusion

The development of the ZCB as a demonstration project of the principles of sustainable design in practice, provides the park with a unique, educational and public-oriented focus. This has resulted in the park becoming a vehicle for demonstrating how the principles of sustainable design should be applied to both buildings and their immediate context. The park has unique and distinctive characteristics and is a project which uses the entire site to inform the public and enhance public awareness of the principles, message, and both the physical and visual characteristics of sustainable development as well as the potential that sustainable design has to meet and exceed the community expectations. The park would therefore enhance urban life while simultaneously being kind to and gentle with the existing environment.


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Figure 23
Urban Forest Walk


Figure 24
Urban Forest Trees, Whips and Seedlings


Figure 25
Urban Forest

Gabion wall formed from demolition and construction debris

Benches made from naturally fallen trees

Recycled glass bench and reuse of formwork panels for carpentry works

Bamboo flooring

FSC certified timber for timber decking

Eco-pavers made from recycled aggregates

Material Use in the ZCB

The ZCB used recycled, rapidly renewable and sustainable materials in its construction. Forest Stewardship Council (FSC) certified timber was used, for example, for hardwood timber decking at the entrance and multi-purpose hall, trellises, and external shading fins. Recycled materials include eco-pavers in the outdoor and landscape areas, pulverised fly ash as a partial cement replacement for concrete mix used in the building structure as well as recycled glass for interior fixtures. Materials were also salvaged and reused on site. Examples include utilising demolition and construction debris for the construction of gabion walls in the landscape area and the reuse of formwork panels for finished carpentry works. Regional and rapidly renewable materials, with the ability to regenerate themselves in 10 years or less, were also used in the building interior. These include bamboo flooring, panels for finished carpentry and natural linoleum for flooring in the lift car. Low/zero volatile organic compound (VOC) substrates, coatings and adhesives were selected for furniture and fixtures.

A low embodied carbon construction approach was adopted. This included a balanced cut and fill approach for site formation, on-site recycling and the reuse of construction waste. A carbon monitoring programme recorded carbon emissions from various construction activities including on-site machinery fuel consumption as well as the embodied carbon of major building materials.

Waste is sorted for recycling in the daily operations of ZCB.

ECODESIGN OF AN URBAN NATIVE WOODLAND IN HONG KONG

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Summary

The innovative Zero Carbon Building (the ZCB) site development in Kowloon Bay, Hong Kong, included a pioneering urban native woodland (UNW). As part of the development, the principles and objectives of establishing an UNW ecosystem, firmly based on ecological concepts were explained. At an urban site, the UNW would emulate the tropical native woodland, with reference to pertinent attributes, including high species diversity, high vegetation cover with multiple vertical strata and complex interlocking crowns. In addition to biomass structure and morphology, the design was intended to create the constituent ecosystem processes such as energy flux, nutrient cycling, food web formation, and constitute a closely-knit and interdependent ecological community. Native plants were sown with a prepared native soil mix, with composition and properties that would trigger development into mature woodland soil. Environmental benefits, such as biodiversity enhancement, cooling, air cleaning, noise abatement and groundwater recharge, were designed to improve with progressive woodland ecosystem succession. The criteria of selecting 44 native tree species, supplemented by native shrubs, were elaborated. The difficulties in acquiring native trees from nurseries in the region, the measures to overcome the hurdle, and suggestions to improve the supply for future projects, were discussed. The project provided the scientific basis and experience to develop similar projects in Hong Kong, the region and other tropical cities.

Keywords

urban woodland, urban ecology, native species, ecosystem service, biodiversity, cool island

Introduction

In the early 21st century, humanity witnessed two definitive issues in relation to our unremitting population growth: In 2010, we crossed the critical threshold of 50% of the world population living in urban environments (World Health Organization, 2013), and in 2012, we exceeded the alarming total of 7 billion people on the planet (National Geographic, 2012). These two figures translate into a current urban population growth of approximately 60 million per year. The bulk of the upsurge occurs in developing countries where the capability to provide a reasonable quality of life is lacking (World Bank, 2013). Such a phenomenal increase of people choosing to live in cities incurs extensive conversion of nature into built-up areas. More and more people are now sequestered in cities where the conditions for a reasonable quality of life are lacking.

An important ingredient of urban living commonly in short supply is nature. The best surrogate for nature-in-city is urban green spaces (UGS). Urban residents are detached from nature and the deprivation of contact with nature is known to induce physical and mental health problems. The lack of UGS also inhibits air cleaning and cooling functions, causing an aggravation of air pollution and the urban heat island effect. Most cities in developed countries follow a compact mode, often with inadequate provision of UGS. There is a need to enhance the provision of ecosystem services to both urban people and the remaining wildlife.

UGS design in many countries, especially the developed world, tends to follow a manicured, simplistic approach. The limited UGS areas are often covered with artificial paving and/or limited unsealed soil and vegetation. Trees with the most complex growth form and biomass structure can provide the highest leaf area index (LAI), which plays a crucial role in air cleaning, cooling and high-calibre ecosystem services. However, in many UGS, trees are sparingly planted and are often scattered around a typical parkland landscape. Existing woodlands are frequently removed or degraded in the course of urbanisation (Jim, 2011a). Very occasionally, small remnant woodland enclaves are left by default or design (Jim, 2004). Such quintessential pockets of nature are invariably warmly welcomed by people and wildlife, and play key roles in ecosystem services (Tregay, 1979; Kowarik, 2005).

Hong Kong is an ultra-compact city with 7 million people living in only 26% of our small territory of 1,016 km^2. Buildings and roads, leaving little land for open spaces, pervasively cover Hong Kong's built-up areas. Hong Kong's public open spaces provision, at merely 3 m^2/person, is among the lowest in the world compared to cities of a comparable scale (Jim, 2002). To compensate for the grave shortage of UGS, the quality of natural components in Hong Kong could be improved to enhance ecological and environmental functions. A feasible and plausible approach would be to convert some plots into urban woodlands (Weiss et al., 2005) or restore damaged plots (Jim, 2012). This paper intends to explain the rationale, underlying concepts, and the practice of establishing an urban native woodland (UNW) at the Zero Carbon Building (the ZCB) site in Kowloon Bay, Hong Kong.

Native Woodland Design Principles and Objectives

The cardinal design principle was to emulate the natural tropical woodland with reference to high vegetation cover, biomass volume, leaf area index and species-area richness, complex biomass structure, and interlocking crowns and multiple-vertical stratification. A special soil mix was prepared with topsoil and subsoil layers designed to emulate the natural woodland soil profile and composition. This mixture is able to furnish suitable properties to sustain tree growth (Jim, 2003) and provide the basis for transformation into a mature woodland soil. Only native species were to be chosen, with preference to those with high ecological value and ornamental features. The species palette contained trees with differing final heights, tree form, foliage density, flowering and fruiting times, seasonality, and full-sun or shade tolerance (Jim, 1990). The trees were to be planted at a suitable density to create, in due course, the crown interlocking of natural woodlands, and to eventually generate a complex three-dimensional biomass structure.

The project's goal was to create a self-sustaining woodland that requires minimal external input for maintenance, and that will bring a wide range of in situ and ex situ benefits in the long term (Figure 1). The woodland was designed to serve as a habitat island with suitable food, shelter and roosting provisions to offer wildlife a foothold or refuge in the heart of the city. The wildlife residents or visitors are expected to contribute to the on-going maintenance and enrichment of urban biodiversity (Alvey, 2006). Finally, the woodland was designed to trap and convert an increasing quantity of solar energy through the food chains and webs to sustain ecological organisation and processes.

As the woodland ecosystem succession progresses, the energy transformation flowing through multiple trophic levels should demonstrate increasing efficiency and internal order. Correspondingly, increases are expected in nutrient content, biomass content and complexity, biodiversity, energy and nutrient capital accumulation. The ecosystem should gradually optimise its internal control by negative feedback mechanisms, leading to upgrading in stability and equilibrium. The woodland should progressively bring nutrient capital accumulation, and an active internal nutrient cycle; characterised by efficient utilisation, safe storage (mainly in living biomass), and reduced nutrient export.

The woodland was designed to gradually develop complex detritus food webs made up of decomposers to break down organic litter and release available nutrients. A closely-knit and interdependent community should duly form. In time, this should raise the carbon sequestration capacity associated with the conversion of inorganic nutrients, with the help of solar energy, into the organic tissue of trees, undergrowth plants, litter, soil microbes, and humus.

The woodland should generate its own microclimate under the closed canopy, with a lower maximum and higher minimum temperature, a narrower diurnal and seasonal temperature amplitude, and clean, fresh and fragrant air. These pleasant environmental benefits should spill to adjacent areas around the site. The cool-island effect, especially in summer should be notably felt and appreciated. Air quality at and around the site also should also be improved by the absorption of gaseous pollutants and the filtering and trapping of particulates. Traffic and ambient noise (sound energy) should be absorbed and dissipated by tree clusters.

Trees employ solar energy to drive evapotranspiration, resulting in significant air cooling due to absorption of latent heat of vaporisation, and contributing to amelioration of the urban heat island effect. The woodland should also generate a woodland hydrological cycle, with notable infiltration of water into the soil and, thereafter, further downward percolation to recharge the groundwater.

The woodland should offer a visual landscape delight and an amenity for thousands of inhabitants and workers in the surrounding high-rise and high-density buildings. It should furnish a pleasant, tranquil and safe venue for passive recreational and teaching/learning uses. Overall, the woodland should present a high-calibre nature-in-the -city pocket, and emulate nature in terms of morphology, physiology, structure and function.

Native Tree Species and Native Soil

Choosing the right tree species and providing high biodiversity were pertinent considerations. The right species combination triggers initial woodland establishment and subsequent spontaneous ecological succession, leading eventually to a stable and mature woodland ecosystem (Jim, 2011b). The candidate species for the UNW at Kowloon Bay were carefully selected with reference to final dimensions, tree form, ecological functions, ornamental features, and suitability for growth in the urban setting.

Most landscaping works in Hong Kong and the region focus on exotic-ornamental species which means a native tree planting palette required to form an UNW was not available. About 200 native tree species were screened for suitability in this urban woodland use (Figure 2). Preference was accorded to species with conspicuous seasonal foliage colour changes, attractive blooms or fruits, and appropriateness for indigenous wildlife in terms of food supply and shelter (Jim, 1990). The need to emulate high natural biodiversity (Alvey, 2006) necessitated the adoption of a relatively wide range of species. A recommended list of 44 species (Table 1) was developed to source the necessary planting materials. Due to the limited supply of native trees in the region, different nurseries were sourced (as anticipated).

With regard to planting material quality, standard sized trees were favoured, with the specification that they have a properly secured root ball not less than 600 mm wide and 400 mm deep, and properly wrapped in Hessian or a similar permeable material (or held in containers). The trunk diameter was to be no less than 50 mm measured at 100 mm above the ground. These trees were to be more than 1,500 mm tall, with one sturdy and straight stem, and capable of standing firmly without mechanical support. The balanced crown was to have a well-spaced branch scaffold. The trees were to be free of structural and health problems, such as crossed branches, v-crotch, included bark, injuries, old wounds with a diameter exceeding 20 mm, unhealed or decayed wounds, pest infestation and diseases, and were supposed to be generally vigorous and robust.

A native woodland needs be complemented by a substrate of native soil. The Kowloon Bay site soil contained fill materials, mixed with construction rubble, which is unsuitable for trees. It was to be replaced down to 1 m in depth by a soil mix of completely decomposed granite enriched with mature compost. It would therefore emulate local natural woodland soil in terms of composition and layering (soil horizons) (Jim, 2003). Topsoil was to be amended with compost to emulate the natural A horizon, and the subsoil was to have less compost, to emulate the natural B and C horizons. The soil mix was designed to provide good drainage to forestall excessive moisture accumulation or waterlogging.

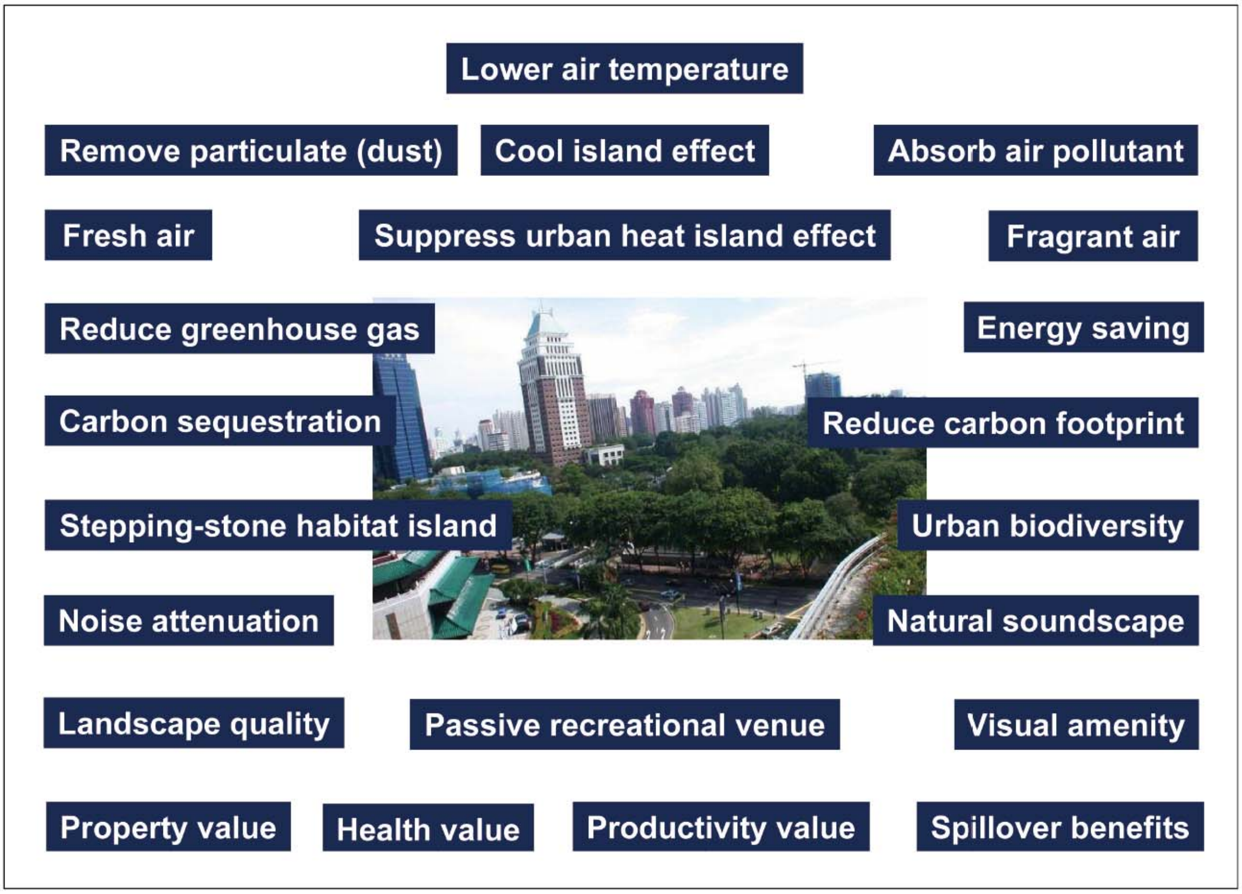

Figure 1 Multiple environmental and socio-economic benefits of urban woodland

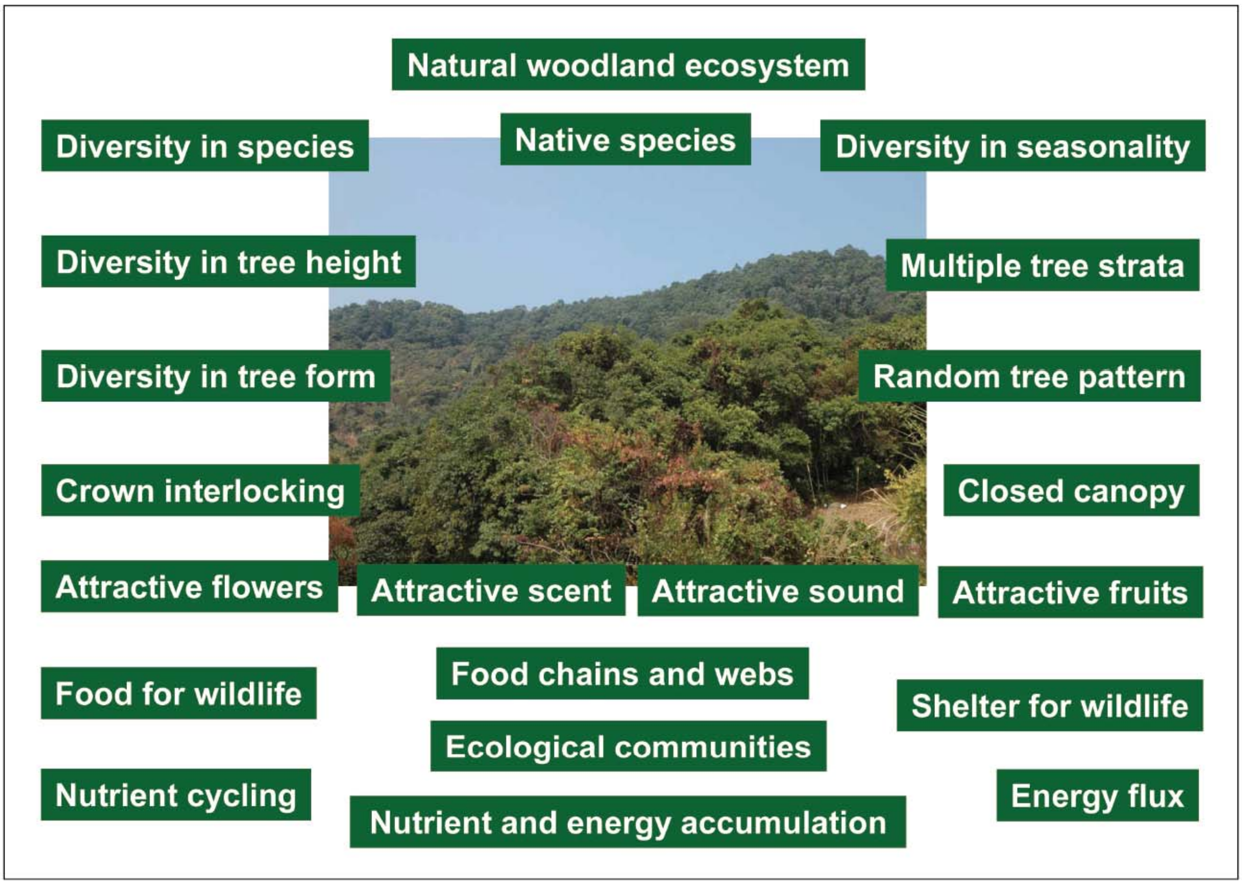

Figure 2 Multiple criteria for tree species selection and layout for the urban native woodland

Table 1 Recommended list of 44 native tree species to create an urban native woodland at the ZCB site in Kowloon Bay, Hong Kong

No.	Scientific name[a,b,c]	Common name	Stock sized	Final sizee	Seasonality	Notable flower	Flower colour
1	*Alangium chinense*	Chinese Alangium	LS	small	deciduous	yes	white
2	*Antidesma bunius*	Chinese Laurel	ST/SD	small	evergreen	no	N.A.
3	*Aquilaria sinensis*	Incense Tree	LS	small	evergreen	no	yellowish green
4	*Artocarpus hypargyreus*	Silverback Artocarpus	SE	medium	evergreen	no	N.A.
5	*Bauhinia 'Blakeana'*	Hong Kong Orchid Tree	ST	medium	evergreen	yes	purple
6	*Bauhinia purpurea*	Purple Camel's Foot	HS/ST	medium	deciduous	yes	pink
7	*Bischofia javanica*	Autumnn Maple	HS/ST	large	deciduous	no	yellowish green
8	*Bridelia tomentosa*	Popgun Seed	LS	small	evergreen	no	blue-green
9	*Camellia crapnelliana*	Crapnell's Camellia	LS	large	evergreen	yes	white
10	*Camellia granthamiana*	Grantham's Camellia	SE	small	evergreen	yes	white petals
11	*Camellia hongkongensis*	Hong Kong Camellia	LS	medium	evergreen	yes	red
12	*Castanopsis fissa*	Castanopsis	ST	small	evergreen	yes	yellow
13	*Celtis sinensis*	Chinese Hackberry	ST	large	deciduous	no	N.A.
14	*Cinnamomum burmanii*	Cinnamon Tree	LS	medium	evergreen	no	N.A.
15	*Cinnamomum camphora*	Camphor Tree	ST	large	evergreen	no	N.A.
16	*Cleistocalyx operculatus*	Water Banyan	ST	small	evergreen	yes	white
17	*Cratoxylum cochinchinense*	Yellow Cow Wood	ST	small	evergreen	no	red
18	*Dalbergia assamica*	South China Rosewood	HS	medium	deciduous	yes	white
19	*Elaeocarpus chinensis*	Elaeocarpus	ST/LS	small	evergreen	no	N.A.
20	*Ficus microcarpa*	Chinese Banyan	HS/ST	large	evergreen	no	N.A.
21	*Ficus subpisocarpa*	Superb Fig	SE	medium	deciduous	no	N.A.
22	*Ficus variegata*	Common Red-stem Fig	HS	large	deciduous	no	N.A.
23	*Ficus variolosa*	Variedleaf Fig	SE	small	deciduous	no	N.A.
24	*Ficus virens var. sublanceolata*	Big Leaf Fig	HS	large	deciduous	no	N.A.
25	*Garcinia oblongifolia*	Lingnan Garcinia	LS	small	evergreen	yes	orange or yellowish
26	*Ilex rotunda var. microcarpa*	SmallFruited Holly	LS	medium	evergreen	no	N.A.
27	*Liquidambar formosana*	Sweet Gum	HS	large	deciduous	no	yellow
28	*Litsea cubeba*	Fragrant Litsea	SE	small	deciduous	yes	white or pale yellow
29	*Litsea glutinosa*	Pond Spice	ST/LS	medium	evergreen	yes	yellow
30	*Machilus breviflora*	Short-flowered Machillus	ST	small	evergreen	no	N.A.
31	*Machilus chekiangensis*	Zhejiang Machilus	HS	medium	evergreen	no	N.A.
32	*Machilus chinensis*	Hong Kong Machilus	SE		evergreen	no	N.A.
33	*Machilus velutina*	Wooly Machilus	LS	medium	evergreen	no	yellow
34	*Manglietia fordiana*	Manglietia	HS/SE	large	evergreen	yes	white (pink tinge)
35	*Pyrenaria spectabilis*	common Tutcheria	SE	medium	evergreen	yes	yellow
36	*Pyrus calleryana*	Callery Pear	SE	small	deciduous	yes	white
37	*Reevesia thrysoidea*	Reevesia	ST	small	evergreen	yes	white
38	*Rhodoleia championii*	Rhodoleia	SE	medium	evergreen	yes	red
39	*Sapium sebiferum*	Chinese Tallow Tree	LS	small	deciduous	no	N.A.
40	*Schefflera heptaphylla*	Ivy Tree	LS	medium	evergreen	no	white
41	*Schima superba*	Schima	LS	large	evergreen	yes	white
42	*Sterculia lanceolata*	Scarlet Sterculia	ST/LS	medium	evergreen	yes	purplish red
43	*Syzygium hancei*	Hance's Syzygium	SE	medium	evergreen	no	white
44	*Viburnum odoratissimum*	Sweet Viburnum	ST	medium	evergreen	yes	white

[a] The species have been chosen based on three cardinal criteria: (a) diversity of tree final size and form; (b) ornamental flower; and (c) food and shelter to attractive native wildlife into the city.

[b] Native species included in the recommended list but planting material could not be sourced: Aporusa dioica.

[c] Not native species but included in the planting list: Bauhinia variegata, Lagerstroemia speciosa, Osmanthus fragrans, Plumeria rubra and Tabebuia impetiginosa.

[d] Refers to the size of planting materials acquired from tree nurseries: HS for heavy standard, ST for standard, LS for light standard, and SE for seedling.

[e] Final tree height: small < 7 m, medium 7-12 m, and large > 12 m. The planting pattern should be random, with small tree interspersed amongst the medium and large trees.

As the woodland matures, the soil should improve progressively in physical, chemical and biological properties. Organic matter accumulating on soil surface as litter should form the O horizon, and its decomposition would generate humus to move downwards, to stay mainly in the A horizon. Soil organisms, including earthworms, should increase in number and activity and participate in decomposition, nutrient cycling and energy recovery. The formation of colloidal humus and clay minerals should enhance the nutrient holding and exchange capacity. The gradual improvement in soil structure should, therefore, facilitate drainage, aeration, storage of plant available moisture, and root growth.

Site Characteristics, Preparation and Planting

The square shaped site of an approximate 1.5 ha area is embedded in the middle of an industrial district in Kowloon Bay near the old Kai Tak Airport. Recently, the area has been redeveloped into a secondary commercial district. A large shopping mall and office buildings adjoin the site. The neighbourhood is characterised by a high-density, high-rise matrix, with little open space. The new green site should denote a relief and precious solution space in this regard.

The ZCB allowed a nature-in-city enclave in the district. The flat, reclaimed land facilitates tree planting and maintenance, and easy use by visitors. With roads on all four sides, the island site is readily accessible by vehicle or on foot. As much as 50% of the land is devoted to greening to serve as a surrogate UGS. The UNW site occupies the south part, with an extension at the east side, taking up 3,000 m^2 or 20% of the site area. Despite the relatively small site, it has sufficient space to develop a successful UNW (Honnay et al., 1999; Godefroid and Koedam, 2003).

A total of 222 native trees from 44 species were chosen for the UNW planting, accompanied by native shrubs, equivalent to a relatively high stocking rate of 450 trees/ha. The landscape contractor initially encountered difficulties in sourcing native trees from nurseries in the Pearl River Delta. As landscape use of native trees is not widespread in the region, many nurseries do not stock them. After contacting more suppliers, most recommended species were successfully acquired. The preference for heavy standard and standard trees by the developer could not be entirely met. Some species were light standard and seedling sizes, which were found acceptable for a created woodland project.

The replaced site soil provided a favourable substrate for woodland establishment. Trees were planted in a random pattern, and those with large final size were interspersed amongst medium and smaller trees to emulate the natural three-dimensional woodland structure. As the trees mature, a dense main canopy should be formed, supplemented by a sub-canopy (smaller). Emergent (above canopy) trees should then form a multiple-layered biomass structure characteristic of tropical woodlands. The quality of planting materials varied with some trees displaying excessive pruning and removal of branches. It will take some years for them to recover to a more natural tree form and scaffold. The inadequate supply prevented a rigorous screening to eliminate more of the sub-standard planting materials.

Native shrubs were also planted, initially at a high density between the trees. This measure was designed to protect the soil against rain splash and erosion from heavy rains, and should provide a green cover for appreciation by visitors. As the woodland canopy closes in due course, the reduction of sunshine will likely induce a decline of some shrubs. The ground vegetation stratum is expected to change with progressive modification of the woodland floor microclimate, soil, light conditions, natural seed rain, and seeds and plants that arrive at the site during woodland management and use.
In the establishment period, the normal range of silvicultural care will be applied. This includes supporting and adjusting the young trees with ties or props, irrigation, weeding, fertilizer application, and treating diseases and pests. After attaining maturity, the woodland will need significantly reduced artificial input. It is expected to sustain itself through internal processes and interactions with the external environment (Hedblom and Söderström, 2008).

Conclusion

The bold vision of the client in accepting the innovative and locally untested idea of planting an UNW at the ZCB site was the most significant step of the project. New ideas are often nipped in the bud and may not see the light of the day. Even though the notion of establishing native woodlands in built-up areas has been promoted for some years, it has not been able to gain acceptance in Hong Kong. The ZCB project management accepted the challenges and obligations of a being a pioneer and bringing this brainchild to fruition. It has set a fine example which will hopefully be repeated in other parts of Hong Kong and elsewhere. The woodland establishment has verified the successful conversion of ecological engineering concepts into ecodesign and ecopractice. Based on the experience and findings of this study, this innovation could be propagated to spread the benefits to more places and people. In addition to new development land, suitable parts of currently existing open spaces could be transformed into woodlands.

The experience in tree acquisition has emphatically informed the landscape industry of the need to tackle the bottleneck in the quantity of quality of native tree supplies. There is clearly a need to shift from the routine supply-dominated standard to a demand-led scenario if native trees are to be more widely used in urban landscaping. Large projects should pre-order the required trees, and develop a consumer-supplier cooperative. The consumer can then determine species composition and production methods to ensure the nurturing of strong and healthy trees. In return, the supplier would receive better prices and partial prepayment, and a guarantee of purchase if the products meet the quality specifications. After all, every link in the landscape industry matters in bringing high quality greenery to our community.

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Water Management at the ZCB

ZCB reduces water demand through the use of waterless urinals, low-flow faucets and toilets. Portable water use is also reduced for outdoor irrigation through the use of a grey water recycling system that treats water collected at sinks and basins as well as a black water recycling system that collects and treats waste water from the toilets. There is also a stormwater harvesting system to collect, treat and store stormwater for irrigation.

A constructed wetland system captures rain and subsurface flow treats grey water and stormwater whilst also making use of recycled debris/gravel at its base. The landscaping/non-building areas of the site are pervious to minimise surface water run-off.

Constructed Wetland system with sub-surface flow to treat grey water and stormwater

Eco office and indoor exhibition space

Functions of the ZCB

The ZCB is:

- An exhibition centre which showcases eco-building design and technologies to the construction industry both locally and internationally;
- An education centre to raise community awareness of sustainable living in Hong Kong and to promote behavioural change;
- An information centre to disseminate information on the latest green building technologies and practices as well as the performance evaluation results of the ZCB to various industry stakeholders

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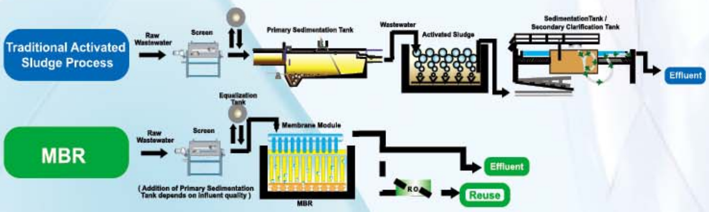

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