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Building information modelling (BIM) for sustainable building design

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Abstract

Purpose – Because of global environmental concerns, sustainable design has become a mainstream building design goal in recent years. Sustainable development is even more urgent in the light of global climate change. This paper aims to examine the contributions which building information modelling (BIM) can make to the production of sustainable building designs.

Design/methodology/approach – Various research methodologies have been adopted, including literature review, design tool analysis, a case study and structured face-to-face interviews. Data collected were synthesized as part of the research process.

Findings – BIM is found to be ideally suited to the delivery of information needed for improved design and building performance. Two most significant benefits of BIM for sustainable building design are: integrated project delivery (IPD) and design optimization. However, there are also barriers to adopting BIM for sustainable design.

Research limitations/implications – This paper does not attempt to address all aspects of BIM functionality because the scope of BIM is very great and the resources of this research were limited.

Practical implications – Successful implementation of BIM is able to eliminate the extra cost of design changes during the subsequent phases of construction process. BIM, therefore, is also capable of enhancing the project delivery culture in future.

Social implications – BIM solutions can contribute to the selection of best solutions to reduce energy and resources consumption. This new technology and the approach also can generate the need of more innovative professionals and job opportunities.

Originality/value – This paper investigates the contribution of BIM to sustainable buildings from the perspective of design performance and improved communication and coordination.

Keywords Building information modelling, Sustainable design, Sustainable building rating systems, Design for quality, Technological innovation, Sustainable development, Design

Paper type Research paper

1. Introduction

Whereas society and technology are developing rapidly, the physical environment of our planet is deteriorating. Data from the Intergovernmental Panel on Climate Change (IPCC, 2007) estimates that global average surface temperature will rise between 1.4°C and 5.8°C by the year 2100 whereas the average temperature rise during the last century averaged only 0.74°C.

Buildings cannot escape their responsibility in contributing towards this environmental deterioration. Construction contributes to the loss of agricultural land

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and forests, to air pollution and the industry is a major user of the world's non-renewable energy sources and minerals (Spence and Mulligan, 1995). The US Green Building Council (USGBC, 2009) data shows that buildings in the United States consume 30 percent of the world's total energy and account for 48 percent of greenhouse gas (GHG) emissions in the US.

The pursuit of sustainability has become a mainstream building design objective. In 1987, the Brundtland Commission offered the following widely accepted definition of sustainability, "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Many countries have established policies promoting sustainability in terms of preventing environmental degradation, e.g. the Hong Kong Government has enacted the Buildings Energy Efficiency Ordinance prescribing minimum energy efficiency standards for key building services installations (Council of Sustainable Development, 2011).

Building Information Modeling (BIM) is a new and innovative technology, which has emerged in recent years and makes possible the efficient achievement of more sustainable designs. The US National BIM Standard (2007) defines BIM in three dimensions:

(1) The Building Information Model (a product) is a structured dataset describing a building;

(2) Building Information Modeling (a process) is the act of creating a Building Information Model;

(3) Building Information Management (a system) comprises the business work and communication structure that increase quality and efficiency.

It is believed that BIM is a critical element in reducing industry waste including wasted energy, adding value to industry products and decreasing environmental damage. Research on the extent of the contribution, which BIM can make to the sustainable design of buildings is well worthwhile, at the same time increasing awareness of the main capacities of this new technology and its potential contribution towards sustainable development.

1.1 Aim and objectives

The aim of this paper is to introduce BIM enabled sustainable design and to explore how BIM can potentially facilitate and benefit sustainable design. The objectives of the research consist of:

- Investigation of the BIM contributions to sustainable building design.
- Analysis of the benefits and obstacles of using BIM to support sustainable design.
- The provision of recommendations on how to apply BIM to sustainable design.

2. Research methodology

The research methodology includes a literature review, design tool analysis, case studies and interviews. The literature review studied of the significance of sustainable design as well as the definition and application of BIM. The BIM-based analysis tool "ECOTECT" was studied in-depth in relation to achieve design sustainability. A Hong Kong building case study was included to test the hypothesis that the use of BIM can

promote sustainable design. Structured face-to-face interviews were carried out with BIM professionals including architects, clients, engineers, consultants and the government to collect opinions on the benefits of BIM for sustainable building design and obstacles to its use.

3. Literature review

In this section, the definition of "sustainable design" and Building Information Modelling is given. Several sustainable building rating systems which provide benchmarks for sustainable construction are also introduced and compared.

3.1 Sustainable design

In this time of a rapidly rising world population, with its increased demand for scarce resources, and continued pollution, sustainability is quickly becoming the dominant issue of our era. The American Institute of Architects (AIA) defined sustainability as "the ability of society to continue functioning into the future without being forced into decline through exhaustion or overloading of the key resources on which that system depends" (Mendler *et al.*, 2005). In 1998, John Elkington introduced the idea of "the triple bottom line" (Figure 1): economic, social and environmental considerations in his report "Cannibals with Forks".

There is no consensus on the definition of sustainable construction. However, the common interpretation of sustainability within the construction industry is the provision of buildings that use less virgin material and energy, and produce less pollution and waste (Zimmermann *et al.*, 2005; Szokolay, 2004). The Hong Kong Housing Authority describes sustainable construction as follows (Lee, 2008):

- Environmental sustainability – we have to build, upkeep and manage our estates with efficient use of natural resources and minimize the impact on environment.
- Social sustainability – we have to nurture social cohesion and provide a safe and healthy environment not only to our tenants, but those working on construction sites and day to day management of our estates as well.
- Economic sustainability – we have to build cost-effectively while functionally meeting users' requirements, keep our operating costs low, extend the service life of our estate through Total Maintenance Scheme and enforce tenancy control for best utilization of existing stock.

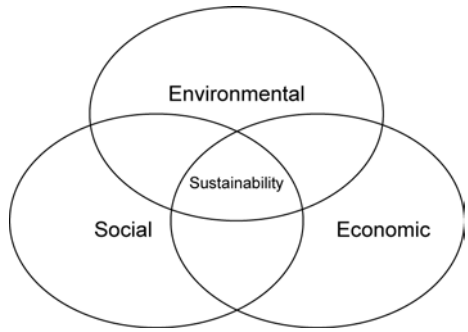


Figure 1.
Triple bottom line

3.2 Sustainable building rating systems

With increased emphasis on sustainable building design, various countries have developed respective rating systems in the last two decades. There were already over 34 green building rating systems or environment tools available on the market by 2006 (Fowler and Rauch, 2006). This paper discusses and compares three systems widely used in the UK, the USA and Hong Kong to highlight their working principles (Table I):

(1) Building Research Establishment's Environmental Assessment Method (BREEAM).

(2) Leadership in Energy and Environmental Design (LEED).

(3) Hong Kong Building Environmental Assessment Method (HK-BEAM).

The reason for concentrating on these systems is that BREEAM and LEED are the first batch to be developed, and HK-BEAM is widely used in Hong Kong.

BREEAM (n.d.) – the first environmental certification system in the world developed by the Building Research Establishment) in 1990, is – widely used in the UK. BREEAM assesses the performance of buildings in eight areas (Table I) and is available for a range of building. Achievement of stated BREEAM ratings is mandatory for several UK organizations such as the Housing Corporation.

LEED is an internationally recognized green building certification system developed by the US Green Building Council (USGBC) in 1998. LEED assesses the degree of green building performance via a 69-points credit system covering six categories and with four levels of LEED certification (Azhar *et al.*, 2011; USGBC, 2009).

The third system HK-BEAM was established in 1996 and is largely based on the BREEAM. HK-BEAM covers all types of buildings and is aligned with local regulations, standards and codes of practice. HK-BEAM assesses the performance of buildings in six areas. Although assessment under HK-BEAM is voluntary, it has become increasingly adopted in Hong Kong in recent years.

3.3 Building information modelling

Different definitions have been given for BIM by different organizations. The US General Service Administration (GSA) BIM Guide (2007) defined Building Information Modelling and Building Information Model as follows:

> Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction

	BREEAM	LEED	HK-BEAM
1	Management		
2	Health and Well-Being	Indoor Environmental Quality (15 points)	Indoor Environmental Quality
3	Energy	Energy and Atmosphere (17 points)	Energy Use
4	Transport	Sustainable Sites	Site Aspects
5	Land Use And Ecology	(14 points)	
6	Water	Water Efficiency (five points)	Water Use
7	Material and Waste	Materials and Resources (13 points)	Materials Aspects
8	Pollution		
9		Innovation and Design (five points)	Innovations and Additions

Table I.
BREEAM, LEED and HK-BEAM assessment list

and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design.

BIM consists of information representing the entire building and the complete set of design documents stored in an integrated database. All the information is parametric and thereby interconnected. Any changes to an object within the model automatically affect the related assemblies and constructions, because the model contains the necessary relational information. This is quite unlike the 2D building representation of conventional CAD-based drawings.

For these reasons, BIM has already begun changing how designers collaborate with consultants and builders, and it also has the capability to guide the industry towards the production of buildings meeting sustainable development goals.

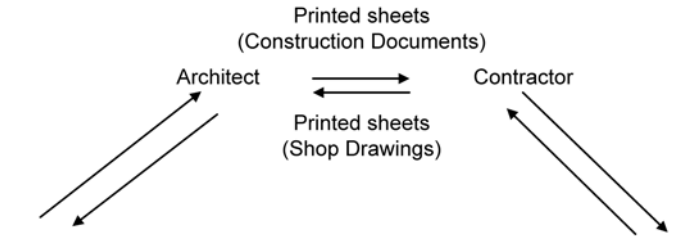
4. Sustainable design with BIM

As the significance of BIM has become increasingly appreciated, more activity in the building industry has focused on BIM and sustainable design strategies (Smith, 2007). A number of published papers on BIM related sustainable design have focused mostly on energy usage analysis alone (Niewoehner, 2010; Schlueter, 2009; Stumpf *et al.*, 2009; Welland, 2009, etc). Some demonstrated how BIM promoted sustainable design in relation to the electrical and mechanical portion of buildings (Middlebrooks, 2008). In this paper, the contribution of BIM to sustainable building design is demonstrated from the two perspectives of Integrated Project Delivery and Design Optimization.

4.1 Integrated project delivery

In the construction industry, a huge problem is "waste and inefficiency", which fundamentally run counter to sustainable development. According to Autodesk Revit's White Paper (2005), inefficiencies, mistakes and delays accounted for $200 billion of the $650 billion spent on construction in America annually, which means almost one third of the total spending is lost to waste.

The industry's traditional design and documentation process (Figure 2) shows that design is a cyclical process and a design needs continuous refinement. As ideas and information are shared and coordinated with the entire project team (consultants, architects, contractors and subcontractors), each project stakeholder makes adjustments to his part of the project. Within this entire chain of information



Source: Krygiel and Nies (2008)

Figure 2.
The traditional method of design review

sharing, there are many opportunities for miscommunication and in fact much of the information is redundantly reproduced as a means of preventing or checking for errors.

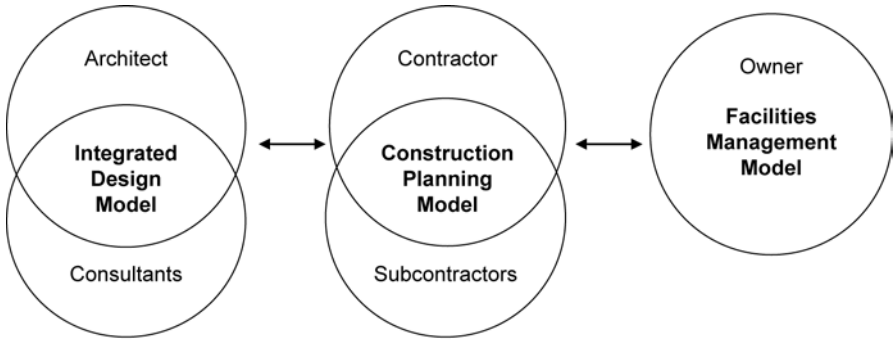
If however, the BIM-based method (Figure 3) is adopted, much of the redundant effort can be eliminated leading to improved communication, and more time focused on improving the design and expediting the construction.

A BIM methodology seeks to adapt to the availability of several layers of information, allowing new methods of data exchange and communication amongst all the stakeholders in a project (Figure 3). The layers of design required in modern projects are many, including structure, landscape, data, heating, cooling, plumbing, power, lighting and so on. The number of layers and the complexity of interactions between them suggest the need for an integrated approach to design. An integrated design model would allow for structural analysis, building performance analysis, MEP (Mechanical, Electrical and Plumbing), material usage analysis, GIS, etc. Integrated project delivery with BIM can reduce the risks and the duration of a project, which subsequently reduces costs and improves project quality and lifecycle performance (Kymmell, 2008).

The Singapore government has made good progress with Integrated Project Delivery (IPD) through the establishment of the Construction and Real Estate Network (CORENET, n.d.), which provides information services, integrated submissions and IT standards to the industry. The CORENET e-Submission system (eSS) enables the submission to regulatory authorities of project related electronic plans and documents for approval. Its Integrated Plan Checking System automates the checking processes for various plan types. Any areas of non-compliance are detected and amended earlier in the design process resulting in fewer re-submissions and designs helping to avoid such as building safety compromises. This approach deliveries sustainable construction processes by reducing rework and thereby also minimizing materials wastage.

4.2 Design optimization

Design optimization is the second important contribution of BIM to sustainable design. Table II illustrates the BIM workflow for sustainability purposes and the BIM software available in the market today. There are two steps. Step 1 is the creation of basic models using the appropriate inherent BIM software; Step 2 is to export these models to BIM-based analysis tools as appropriate. This is explained in detail below, using



Source: Krygiel and Nies (2008)

Figure 3.
An integrated approach to design review

Table II.
Sustainable design with BIM

	Step 1: Inherent BIM Features	→	Step 2: BIM-based Analysis Tools
Software	Revit, ArchiCAD, Bentley, Graphisoft, TriForma (Beta), etc	→	Ecotect, IES-VE, Green Building Studio (GBS), EnergyPlus, TRACE700, eQUEST, etc
Green Strategies	Building Orientation; Building Massing; Load Data, etc	→	Building Load Calculations; Energy Analysis; Lighting Design; Ventilation; Materials, etc

Autodesk Revit and ECOTECT as examples. Surveys of the various BIM software systems and models can be found in papers and books (Azhar *et al.*, 2011; Kymmell, 2008; Crawley *et al.*, 2005). Some researchers have investigated ways by which BIM can interact with sustainable rating systems. Azhar *et al.* (2011) proved that a number of LEED credits can be gained by appropriately using BIM or BIM-based analysis tools. Biswas *et al.* (2009) described the integration of a sustainability information framework with a BIM application.

Step 1: Inherent BIM features

"Green" strategies using the inherent BIM software such as Revit include selection of the best building orientation and the appropriate degree of massing. Setting building orientation with BIM is introduced here for illustration.

Building orientation for sustainable design involves the positioning of a building on site relative to the path of sunlight. How a building and its windows interact with the sunlight has a big effect on the energy efficiency of the building systems and the comfort of its occupants. Both factors earn points in the LEED checklist. By making the maximum use of natural recourses, the need for man-made systems and energy usage can be reduced, thereby improving the sustainability rating of the design.

Optimal building orientation generally means setting the long side of the building(s) to face south if possible within the constraints of the site. BIM automatically contains the data needed for finding solar south. First, establish the location of the project. Figure 4 shows the longitude and latitude of a project located in Hong Kong provided in Autodesk's Revit Architecture. Second, calculate the angle of declination of the project, and rotate the project to the proper angle. Figure 5 shows the project before and after proper rotation relative to solar south and how the shadows change during the daytime. Not only the shading is impacted, but also is the heat gain and day lighting inside the building. Proper building orientation is fundamental to the optimal design of heating and cooling plants, including minimizing energy usage costs.

Step 2: BIM-based analysis tools

Currently there are three commonly used BIM-based sustainability analyses software on the market. These are: Autodesk ECOTECT, Autodesk Green Building Studio (GBS) and Integrated Environmental Solutions (IES) Virtual Environment (VE). Some authors have emphasized on the integration of BIM with GBS or VE (Azhar *et al.*, 2011; Stumpf *et al.*, 2009; Rundell, 2007). In this paper, the application of Autodesk

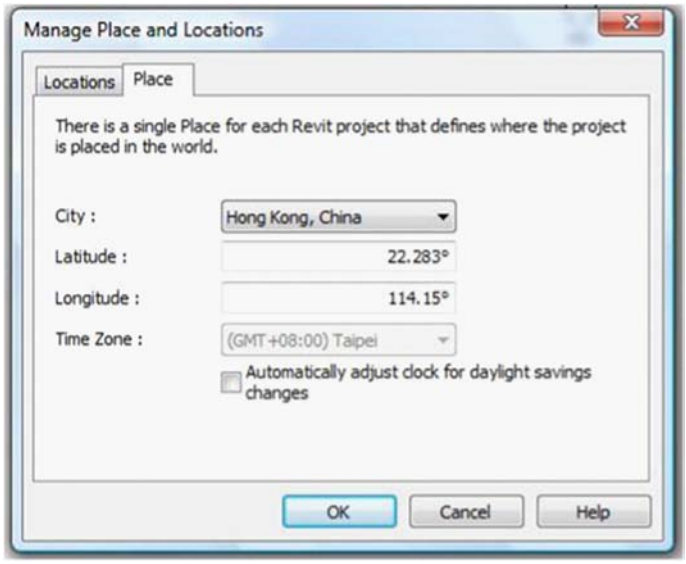


Figure 4.
Locating the project in Revit Architecture

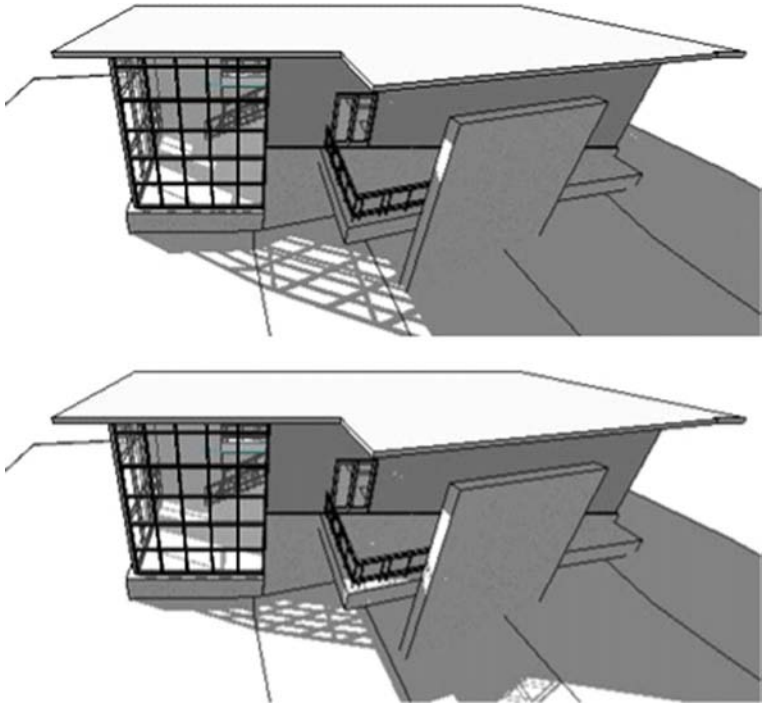


Figure 5.
Changes in shadows of the project before and after proper rotation to solar south in Revit Architecture

ECOTECT is focused upon. ECOTECT is a complete building design and environmental analysis tool covering a wide range of simulation and analysis functions allowing designers to work easily in the 3D context (Autodesk, 2009). Table III shows how ECOTECT aids the compilation of Sustainable Building Rating Systems requirements using LEED. The key features of ECOTECT include shading design, solar analysis, lighting design, thermal analysis, ventilation, and resource management. In this paper, the contribution of solar analysis to energy saving is presented as an example of how BIM can promote sustainable building design.

Energy – solar analysis. Energy efficiency is a factor in rating the sustainability of a building. In the LEED system, "Energy and Atmosphere" accounts for 17 points, the top most of all rating categories. Different BIM-based Analysis software systems have different analysis functions. For example, Green Building Studio (GBS) helps to assess multiple design alternatives while ECOTECT is more appropriate for detailed design visualization and simulation of the performance of a specific design (Autodesk, 2010). Stumpf *et al.* (2009) described a case study of the use of GBS for a whole building energy analysis, which showed that the BIM-based energy simulations can be completed more quickly and earlier in the design process than in the traditional approach.

The authors of this paper studied how "solar analysis" application in building design could achieve energy efficiency. Since the sun is one of the most effective natural energy resources available to buildings, a solar analysis enables the sun's energy to be captured to the maximum possible extent, reducing the man-made energy requirement. ECOTECT was found to be ideal for this purpose.

ECOTECT has calculation and visualization capabilities enabling incident solar radiation falling on any surface or part of the targeted building to be assessed over any period. Designers are able to optimize their design in the following respects:

- Shading design (Figure 6).
- Determine mechanical heating and cooling.
- Optimize location of vegetation and garden layouts.

ECOTECT is able to calculate shading and reflection percentages together with the amount of solar radiation falling on an object (Figure 7), which is excellent for determining the best locations and orientations of solar panels. In addition, as the solar radiation incident on solar collector can also be calculated, it is easy to estimate its energy production throughout the year as a contribution towards the optimization of total energy consumption of the building.

LEED requirements	ECOTECT
Energy	Solar Analysis
Indoor Environmental Quality	
Thermal Comfort	Thermal Analysis
Ventilation	Ventilation and Air Flow
Daylight	Lighting Design
Materials and Resources	Resource Management

Table III.
LEED requirements and ECOTECT

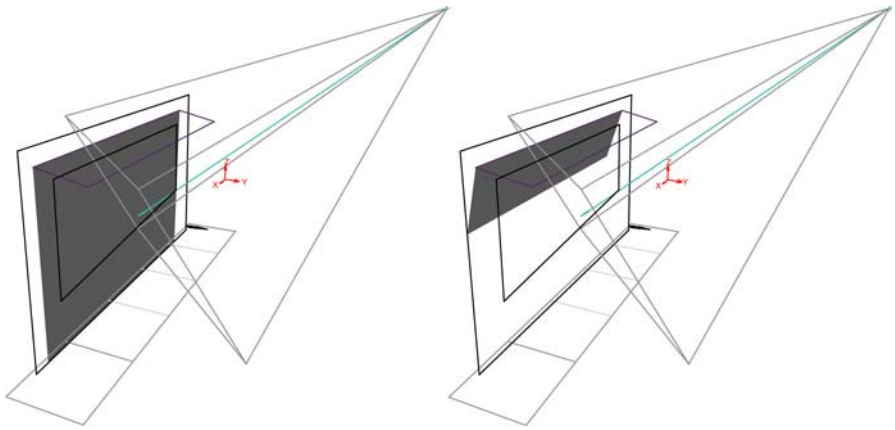


Figure 6.
Shading design in Ecotect with shadows in summer and winter

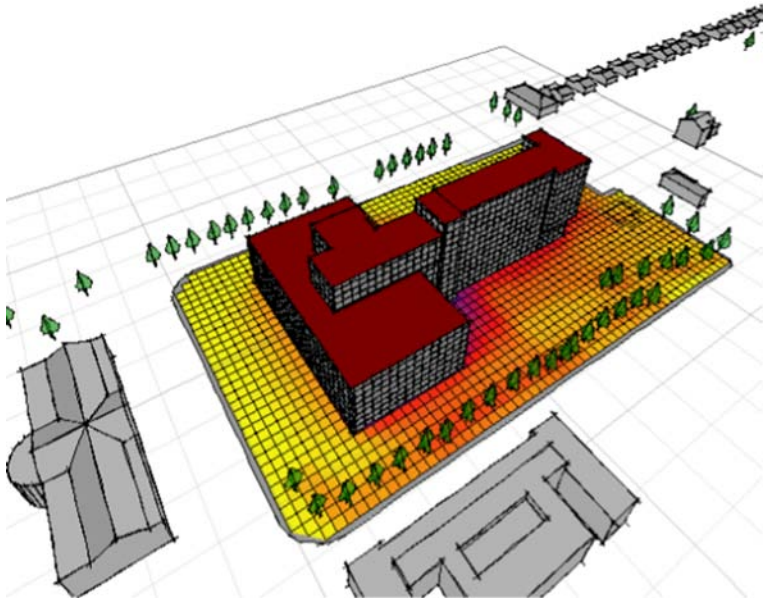


Figure 7.
Map Insolation over the analysis grid in Ecotect

5. Benefits of BIM for sustainability aspects

The integration of BIM during the design stages enables more rational design decisions to be made due to the increased quality, speed and availability of design data. BIM is an excellent tool for achieving a higher triple bottom line, with environmental,

social and economic factors all standing to benefit from a more streamlined design process.

- *Environmental aspect*. The contributions of BIM to integrated project delivery and design optimization as discussed earlier are well recognized as significant in reducing the use of materials and energy. Purpose-built BIM solutions and integrated analysis tools can be applied to the assessment of building performance and the selection of solutions which can best reduce consumption of resources such as energy, water and materials. Wastage due to inefficiencies or mistakes in the project delivery process can also be reduced.
- *Social aspect*. Integrated Project Delivery (IPD) reduces the risk in a construction project by improving communication and collaboration between team members. IPD also improves safety by anticipating problems earlier in the planning stage, e.g. the function of clash detection by combining architectural and MEP models in Navisworks. The quality of the design and construction of the built product can also be improved to provide a better living environment. Furthermore, the growing popularity of BIM will likely lead to an increased number of innovative jobs opportunities via professional BIM consultancy.
- *Economic aspect*. As discussed above, IPD can improve communication and collaboration as well as anticipate problems earlier. This reduces undesirable wastage due to improved construction management and thus reduces project cost (Figure 8). Moreover, BIM helps to optimize the design, reducing capital and lifetime costs through improved material and energy efficiency.

6. Case study

Hong Kong Monetary Authority (HKMA) which is located on floor 77 to 88 of the International Finance Centre II (IFC II) conducted a review of its office environment, including appropriate enhancements to its audio-visual, security, fire safety systems, furniture and finishing, "green office" measures and facilities, and its office ergonomics provisions. Consultants were invited to carry out a professional Due Diligence Study (DDS). ECOTECT was then used by the consultants for their internal reviews and assisted the preparation of the deliverables including the DDS.

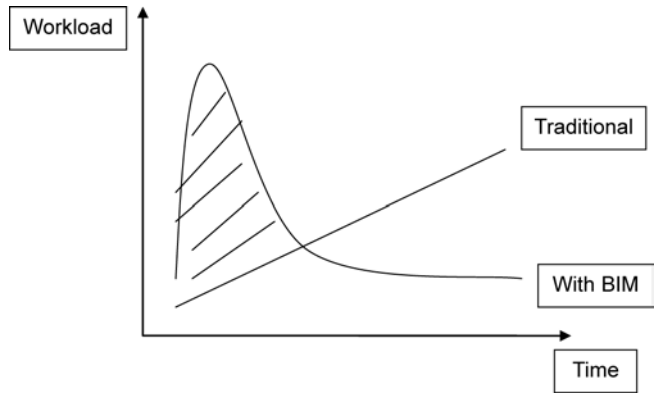


Figure 8.
Comparison of the workload over time under traditional design methods and BIM

As a government department supported by public money, the HKMA always seeks to identify the most cost-effective ways of achieving fully justified and practical improvements that will enhance office efficiency and operational effectiveness. The left hand column of Table IV presents the basic requirements required by HKMA while the right hand column lists the relevant ECOTECT features which could help meet these requirements. This illustrates that BIM tools can serve well for design optimization.

7. Interviews

In Hong Kong, it is encouraging to see more major project promoters with their specific time frames of applying BIM such as Hong Kong Housing Authority, Mass Transit Railway and Hong Kong Science and Technology Park. To consolidate the research findings, five senior professionals substantially involved in BIM projects with the above project promoters in three domains were interviewed. The interviewees represented the roles of BIM consultant, project promoter and client. Due to their different roles in the construction industry, different opinions on sustainable design and the contributions of BIM were received. The obstacles to and the prospects for wider application of BIM were also discussed. The interviews revealed some key views on the application of BIM for sustainable design, as summarized below:

- Sustainability is a very important concept with the building construction industry, basically seen as dividing into environmental, economic and social aspects. Efficient energy use and reduction of CO_2 emissions have always been

	Requirements	With ECOTECT
1	*General Lighting* Review the general lighting and control system for reception, meeting rooms, circulation corridor and general office areas and suggest more energy efficient light fitting/control methodology to be adopted in connection with sunlight utilization with intelligent lighting control system	Lighting design; Solar analysis
2	*Window Blinds* Suggest perimeter window blinds system to control daylight sunlight and solar heat gain entering the building in connection with artificial lighting system to achieve appropriate lighting level and room temperature across the floors to provide the green and comfort office environment	Shading design; Lighting design; Solar analysis; Thermal analysis
3	*Movable Partition Systems and motorized blinds* Review and advise the existing movable partition system and motorised blinds for Meeting Room floors in conjunction with inception design of acoustic and vibration control, with particular emphasis to reduce noise and vibration disturbance to the users and to adjacent floors	Acoustic analysis

Table IV.
Meeting requirements with ECOTECT

key drivers. Materials used and their wastage are also key importance and need to be carefully dealt with in sustainable design and construction.

- BIM could be used to optimize the design and enhance communication and coordination between architects, engineers, contractors, and clients, etc. This leads to better quality buildings, reduces wastage and saves project time. Therefore, BIM makes a great contribution to sustainable design and construction.
- Since BIM is in its infancy, there is a shortage of specialists in its use. Promotions and training efforts should be increased to encourage more people to know, use and apply BIM.
- It is certain that BIM will be more widely used helping to provide more sustainable buildings in future. The design and construction workflow, and even operational management will be planned and controlled with the help of BIM.
- Research and professional development in BIM should focus more on the provisions and management of BIM services contracts and the ways of BIM coordination between consultants and contractor. There are also demands in the industry for the establishment of proper mechanisms and performance indicators to monitor and control the performance of BIM related construction processes.

8. Conclusions and recommendations

Building Information Modeling (BIM) is ideally suited to the delivery of information enabling improved design and building performance. Two major beneficial features of BIM in relation to sustainable building design are those of Integrated Project Delivery (IPD) and Design Optimization. Traditionally CAD-based design requires a great deal of human intervention and the whole process is time-consuming and costly. However, with BIM, designers can optimize the building design efficiently in the very early stages of the whole process and produce a better solution. Table V summarizes the major contributions of BIM to sustainable building design.

		Functions		Benefits		Sustainable achievements
BIM Inherency + BIM-based Analysis Tools	→	3D Model Visualization Clash Detection Compliance with Regulations Energy Analysis; Solar Analysis Thermal Analysis Lighting Design Acoustic Analysis Ventilation and Air Flow Materials/Resource Management	→	Integrated Project Delivery Design Optimization Better Communication and Coordination More accurate and efficient	→	Energy Reduction Water Conservation Wastage Lessen IEQ Improvement

Table V.
Summary of BIM for sustainable design

This research concurs with the previous research findings that lack of interoperability could be a factor limiting the application of BIM in building design and needs to be considered earlier in the planning stage. In addition, the overall practical effectiveness of BIM still needs to be analyzed and validated (Bernstein and Pittman, 2004; Lu and Li, 2011; Moreira *et al.*, 2010; Gu and London, 2010).

Future of sustainable design with BIM

In Hong Kong, the Government attaches great importance to sustainability and BIM has been applied during various stages of building development. The Hong Kong Housing Authority (HKHA) is one of the BIM pioneers in Hong Kong. About 11 HKHA projects had applied BIM at various stages to enhance design and construction by 2011 and their goal is to fully implement BIM for all projects by 2014. An HA IT Manager has claimed that BIM has helped to promote sustainability in their projects (Hong Kong Housing Authority, 2011). In China's 2011-2015 Development Outline, the need to speed up the application of BIM and push forward the establishment of IT standards is stressed. Since BIM has great potential for promoting sustainable building design, it is inevitable that BIM will be more and more utilized in building construction industry.

Nevertheless, there is a common consensus that BIM is currently still immature for its full adoption in the construction industry. Based on this research, some recommendations for the future development of BIM in sustainable building design are as follows:

- *BIM standards*. Though BIM can be used now in a number of ways to support sustainable designs and the process of collaborative project delivery, BIM solutions need to be more integrated in order to achieve seamless interoperability. Therefore, continuous research and development efforts are needed to help improve existing practice and create new applications including the establishment of BIM standards to facilitate interoperability.
- *Industrial culture change*. For construction industry enhancement in the long run, an industry culture change for the promotion of construction IT including BIM is necessary. Tertiary education, professional development and government initiatives are also essential to support any industry enhancement.
- *Training and education*. There is a great lack of well-educated and trained BIM professionals. More training is recommended, therefore, for a range of people in the construction industry. It would be even better if there were more construction oriented degree programmes, which incorporated BIM in the curriculum to a significant degree.

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Appendix. Sample interview questions

- What is sustainable construction in your opinion?
- How important the concept of sustainability in building construction is as far as you concern?
- On what projects have you applied BIM (e.g. Revit Architecture, Ecotect)?
- What is your motivation to apply BIM on your projects?
- Do you think BIM has supported sustainability in your projects? In which aspects?
- What are the benefits of using BIM compare with traditional methods?
- Are there any difficulties in using BIM according to your own experience?
- How do you see the future of BIM in sustainable construction?

(1) Interview with Mr Elvis Li and Mr Rex Lau (BIM consultant)
Company name: Tecton Limited
Position: Vice President, Project Manager

Views on sustainability in building construction industry. When talking to sustainability in building construction industry, Mr Li and Mr Lau listed out two essential points, one is the reduction of energy use and the other is the reduction of wastage. As global warming is getting more and more serious, it is urgent to cut down the CO_2 emission. Since building construction industry contributes to a great amount of energy use in both the construction stage and occupation stage, it must be highlighted when considering sustainability. The second key element is the wastage produced during the construction stage. For example, the completed section dismantled due the change of the design would become the waste. Such waste will take a large percentage of the total waste in Hong Kong and the incorrect disposal of construction waste is the only one, which might cause a penalty by the Hong Kong government. Therefore, reduction of wastage is a key point for achieving sustainability in building construction industry.

Application of BIM. Tecton has applied BIM on more than forty projects since the company set up in 2002 and it is the first BIM consultant company in Hong Kong as well. One famous project is the Beijing World Financial Centre. The products Tecton usually applied on the projects include Revit Structure, Revit MEP, Revit Architecture, Digital Project, Naviswork, IES < VE > and 3DMAX.

Mr Li emphasized that 'BIM is not software. Software is not BIM.' BIM is a process of representation, communication and collaboration. The motivation of Tecton to be BIM consultant basically comes from two factors. One is the manufacture orientation. As structures such as facades could be prefabricated in the factory and then fixed on site, the requirement for the prefabricated component is very rigid, e.g. precise size and coordination of different components. BIM could solve this problem as it can show the 3D drawings of the whole structure.

The second reason is that there is business opportunity existing for operating BIM since BIM is a new approach in the construction industry and has great potential to be widely used.

Views on sustainable design with BIM. Mr Li and Mr Lau have listed out three important areas BIM has contributed to sustainable design. The first one is Computational Fluid Dynamic (CFD) Model used to calculate airflow for mechanical systems, which is related to ventilation and solar heat gain. The second point is that BIM could help to utilize natural resources and thus reduce energy use by optimized the design. Finally, it will cut down CO_2 emissions due the above reasons.

Compare BIM with traditional methods. Generally, when design work is taken with applying BIM, the whole workload will be brought forward compare with traditional design methods. The work usually carried out in the construction stage (e.g. change of the design) must be fulfilled in the design stage due to the use of BIM. Therefore, the workload would be much heavier during the design stage when BIM is used.

However, with BIM it can diminish the risk on the aspects of time, quality and cost. With 2D tools, it might only achieve 30-50 percent quality but with 3D BIM it could guarantee almost 100 percent quality of the project. Take door as example, BIM could show detailed information including the size, material even the supplier in the document. As the documentation is coordinated, consistent and complete, wastages could be reduced and so could be the total cost.

Obstacles when using BIM. As explained above, when using BIM the whole workload is brought forward, architect's tasks would be much heavier during the design stage. One method to solve this problem is to outsourcing the work to a BIM consultant.

Suggestions for future sustainable design with BIM. Though there are already 'Sustainable Building Rating Systems' as HK-BEAM existing, there should be more specific parameters (e.g. for CO_2 emission, energy use) to be set and quantified for sustainable design.

Currently there is no clear flowchart for BIM-based design/construction process. Prioritization should be adopted to establish the flowchart so that each person has clear understanding of his responsibility on the job as well as the time. In this way, BIM could be better utilized for sustainable design.

Interview with Mr Michael Chan (BIM Promoter)
Company Name: Autodesk Far East Ltd
Position: Technical Manager
Views on sustainability in building construction industry. Basically there are three main elements need to be highlighted when referring to sustainability in building construction industry.

(1) It is best to adopt local materials since materials from abroad might not be suited to the local climate and there might lack skilled labor to operate with the unfamiliar materials. Besides, the transportation of materials is not economic and will add to CO_2 emissions.

(2) Optimized design: combination of natural lighting and artificial lighting design (requirements from government, e.g. at least four hours day lighting for classrooms); ventilation requirements; material choosing (good material might be expensive while bad one might be not durable); structural system selection (truss, tent, cable). All of these should be balanced to achieve the optimized design.

(3) Management system in construction stage.

Compare BIM with traditional methods. BIM could help to enhance the communication and coordination between different parties. Traditionally, if there is a change in the design profile, you should draw a new plan (elevation, section), and other drawings (structural, engineering services) should be redrew accordingly. It wastes lots of time as well as materials. However, with BIM, if there is change, you do not have to draw a new plan, other changes will be operated by computer automatically. Architects could perform "what-if" easily just with a piece of computer. It would be very unimaginable that there are no hand drawings on the table in the past. What's more, the change of the architect's drawing could be sent to the civil engineer, mechanical engineer immediately. In this way, the time for coordination is saved.

In some studio, architects have three computers, one for the operation, one shows the 2D drawings, and another shows the 3D drawings. If there is a change in the first one, there the other two would change the drawings as well automatically, which is rather convenient. There are also some situations where architects and engineers works together, engineers could get the revised drawings as soon as architects did some changes.

Besides, as BIM is 3D based rather than 2D, which means it is more visualized, and therefore it is more convenient for all parties to communicate.

Obstacles when using BIM. As BIM is generally a new concept at current stage, not many people have concept about it, let alone to use it fluently. Therefore, training should be arranged since there is a lack of BIM professionals. But training will cost time and money, clients may not be willing to do it.

Future of BIM for sustainable design. BIM would definitely be more and more widely used in the future. Some day the manufacture of buildings could be the same as the manufacture of cars and auto planes due to the benefit of BIM. There will be a complete workflow for constructing a building. Architects, engineers, quantity surveyors might be working in a same team for the common benefit in the future, and a big company would be there comprising both the design and construction teams.

The development of BIM and sustainable construction should be interacted. As BIM could help the buildings be designed and constructed more sustainably, in turn, since the requirement of sustainable buildings is higher and higher, the demand for BIM would also be increased.

Interview with Mr Alex Ho (BIM client)
Company Name: Hong Kong Housing Authority
Position: Manager of Business Process Unit/Construction
Measures taken for achieving sustainability in building construction industry. The Hong Kong Housing Authority has declared in there sustainability report to remain sustainable in three key areas: environmental, social and economic. In order to achieve these goals, HKHA have taken a serious of measures in planning & design stage, construction stage as well as occupation stage. In planning & design stage, HKHA have explored several models of user-oriented neighborhood design for new estates and introduced W-trap in drainage systems; in construction stage, they have extended the use of pre-casting and prefabrication for better quality and caring for the environment; in the occupation stage, Total Maintenance Scheme have been launched to proactively identify maintenance needs. These are only some examples of the measures HKHA have done in recent years. More are available in the paper presented by Mr Daniel Lee from Hong Kong Housing Authority (This reference is provided by Mr Alex Ho).

Views on sustainable design with BIM. According to Mr Ho, they have applied BIM on about twelve projects, mostly seek assistant from BIM consultants. However, this application is limited to setting models or clash detection other than building performance analysis such as the use of ECOTECT. This part of work is still under the duty of architect. However, HKHA is endeavoring to make the application of the BIM analysis tools.

When talking to the motivation to apply BIM on the projects, Mr Ho pointed out two factors, one is reduce wastage and the other is for better or greener design. Both suggested that BIM has supported sustainability in building construction industry

Compare BIM with traditional methods. There are mainly three benefits while applying BIM compare with traditional methods. Firstly, BIM allows for earlier simulation of the design and is more accurate and clearer than that of the traditional design methods. Secondly, because of the first reason, wastage produced in the construction stage could be reduced. Lastly, the function of visualization makes it easier to explain the project to the citizens and contractors and is better to seek comment from them.

Obstacles when using BIM. The application of BIM actually will lead to the change of organization culture, which might take time for people in construction industry to accept and adapt to it. Besides, as most of the BIM software are developed by USA or UK, we have to seek the right to use them in Hong Kong. Moreover, BIM is still a new word to many people even to many professionals in the construction industry, let alone to use it. Even if someone knows how to use it but he (or she) may not able to apply it in the real situation fluently. There is a severe lack of BIM specialists in Hong Kong at current stage.

Future of BIM for sustainable design. Sustainability in building construction industry has already been a hot spot around the world, however, the use of BIM to support sustainable design is not mature at present, especially in Hong Kong. But surely the role of BIM in construction industry will be more and more important, just like the development of modeling in car and plane manufacture. Along with the maturing of the software itself and the BIM specialists, BIM would play a significant role in sustainable design for building construction.

Interview with Dr Stewart Wan (BIM client)
Company Name: Hong Kong Science and Technology Parks Corporation
Position: Manager of the Projects and Facilities Division
Dr Stewart Wan looks after the IT and building projects for the Hong Kong Science Park development and is in charge of the Hong Kong Science Park's IT unit. He has over 15 years experience in electronic and IT infrastructure design and management. The Hong Kong Science Park (HKSTP) as the pioneer of transforming innovation and technological advancement into value creation in Hong Kong started its operation in 2002. Since its inception, Hong Kong Science Park has already embraced the green and sustainability concept in its master plan design.

Currently Dr Wan is also the Board members of The Hong Kong Institute of Building Information Modelling.

What is sustainable construction in your opinion? Sustainable construction aims at reducing the environmental impact of a building over its entire lifetime (i.e. raw materials, delivery, construction, operation, demolishment/renovation), while optimizing its economic viability and the comfort and safety of its occupants. However, sustainable construction is a board term, which consists of multi-dimension of views from the public and users.

How important the concept of sustainability in building construction is as far as you concern? The concept of sustainability in building construction plays an important role in my responsible projects. It drives the master planning of construction, budget control and operation mode.

On what projects have you applied BIM (e.g. Revit Architecture, Ecotect)? Adopt BIM for all capital projects after 2006.

What is your motivation to apply BIM on your projects? Enhance the visualization of design; verify the design before it is built; integrate vertical industries horizontally; extending the core value of BIM to other applications, enhance the level of expectation in time and cost, etc.

Do you think BIM has supported sustainability in your projects? In which aspects? Yes, it can be used to verify sustainable designs basically, e.g. basic solar analysis, shading effect; positioning of features to minimize rework; look and feel in 3D space for features, etc.

What are the benefits of using BIM compare with traditional methods? If the BIM process is managed properly during design stage, the verification could be done easily by comparing with tradition methods.

Are there any difficulties in using BIM according to your own experience? It requires proper management in BIM service contract, coordination with consultants and contractor, etc. Adequate mechanism to control/gauge the performance of BIM is required to establish.

How do you see the future of BIM in sustainable construction? With more integrated solution with various sustainability design tools, BIM will play a core to consolidate all relevant designs into a single model for design, construct and operate.

About the authors

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