On the Exploration of Building Information Modeling Capabilities for Promoting Sustainability-related Practices in Construction Projects: Case Studies in China and USA

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Abstract: - This paper deals with sustainable design and construction, since the interest in and the awareness of green design has grown dramatically in the past several years and the different rating systems used worldwide the main focus will be on LEED; the different LEED certifications available, the process of the certifications, and the criteria on which the certification consider. Additionally, it will relate its new trends with each other by showing how building information modeling can be used to achieve a sustainable design. The powerful tools of building information modeling (BIM) will be discussed that can ease and aid the process of the LEED certification of a building. This paper also reports a demonstration pertinent to the implementation BIM can provide to achieve a sustainable green design. Two case studies are investigated; the first case study is a LEED Gold certified 128-story tower in Shanghai, China while the second is a LEED Platinum certified 13-Story building in San Francisco, USA.

1 Introduction

1.1 Leadership in Energy and Environmental Design (LEED)

Leadership in Energy and Environmental Design (LEED) is a voluntary and consensus-based, market-driven program that consists of a rating system for the design, construction and operation of green buildings. LEED was created by the United States Green Building Council for the purpose of promoting sustainable construction and green buildings. LEED standards allow people to quantify a building's performance and their contribution to sustainability with a score by accumulating points in various categories. The rating system is a group of requirements for LEED certification and it is separated into five main categories (sustainable sites, water efficiency, energy and atmosphere, material and resources, and indoor environmental quality) and two bonus categories (innovation in design or operation, and regional priority). This program allows the participation of various projects such as schools, homes and facilities. A different rating system exist for each of the following: Existing building, Core & Shell, Commercial Interiors, Retail, Homes, Neighbourhoods, Schools, Healthcare facilities.

In 2005, only 2% of non-residential new constructions in the U.S are green building. This is expected to increase to 25% in 2013 [1]. There are currently more than 30000 LEED projects in 114 countries. As illustrated in the figure below, there is an increase for LEED accredited professionals, LEED projects, LEED certified project of 226%, 253% and 200% respectively from 2007 to 2009.
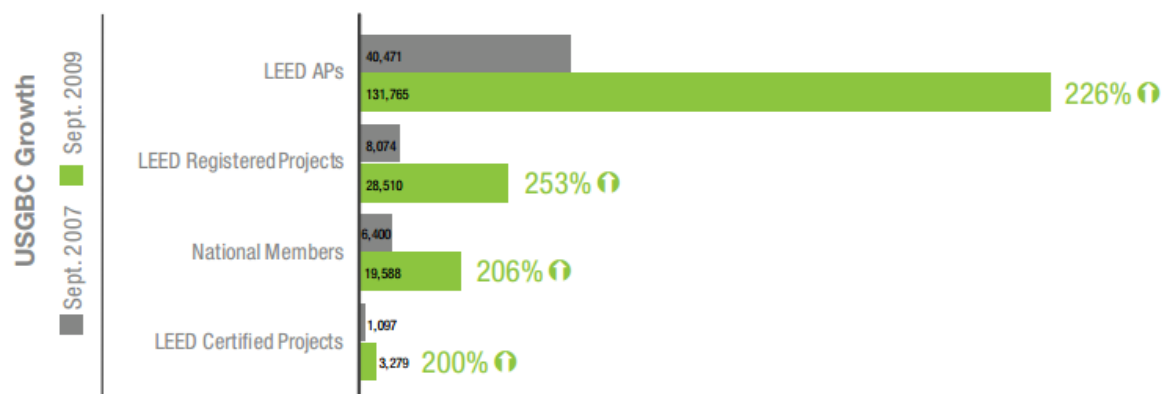

Fig.1: Increasing Trend of LEED [2].

1.2 A Brief History of LEED

The LEED program is continuously growing and changing. This section of the paper will explore the history of LEED, the Canadian version of LEED, the certification process and its advantages and disadvantages. The purpose of this section is not to describe in detail LEED certification but instead, give a general overview of this wonderful framework.

This program was created by United States Green Building Council (USGBC) in 1998 and it is still currently being revised.

The first version of LEED, also known as LEED Version 1.0, started when the USGBC launched it in August 1998. It was one of the first market-driven building assessment system tools for new construction projects. There were a total of twenty buildings that was certified using LEED 1.0 [3]. LEED 2.0 was issued in March 2000 after extensive modifications to the LEED standard. It added a point-based system of 69 points that is divided into the 6 main categories mentioned previously. With this second version, buildings can be branded as Platinum, Gold, Silver and Certified rating.

There are different rating systems depending on the project. LEED version 2.0 has the following categories: new construction (LEED-NC), existing buildings (LEED-EB), core and shell (LEED-CS), and commercial interiors (LEED-CI). LEED 3.0 is the current version of the program that is being used. It focuses on reducing energy use and greenhouse gas emissions. It enhanced the rating system and simplified the certification process with LEED online. It is now based on a 100 (+10 bonus) point system and added other rating systems described below. All LEED procedures described in this paper will refer to the LEED 2009 version.

The LEED program is continuously growing and getting better. LEED 4.0 will expand the rating system to more building types and manufacturing industries. This version is scheduled to be released during the year of 2013. According to the USGBC website, the fourth version will have the following changes [4]:

- New market sectors: data centers, warehouses and distribution centers, hospitality facilities (i.e. hotels), existing schools and existing retail, and LEED for Homes Mid-Rise.
- Increased technical rigor: revisions to credit weights, new credit categories focusing on integrated design, life cycle analysis of

materials, and an increased emphasis on measurement and performance. It emphasizes on energy efficiency by allocating 20% of all points to building energy efficiency.

- Streamlined services: An improved LEED user experience that makes the LEED Online platform more intuitive and introduces tools to make the LEED documentation process more efficient.

1.3 Canada Green Building Council (CaGBC)

The Canadian Green Building Council CaGBC is a non-profit organization which aims to change the industry's environmental standards, to develop best design practices and guidelines, to advocate for green buildings and to develop educational tools about implementing sustainable design and construction practices. Since 2012, the CaGBC has implemented the version of LEED in Canada which is adjusted for the Canadian climates, construction practices and regulations. LEED Canada has currently four rating systems:

- LEED Canada for Existing Building: Operations and Maintenance (EB: O&M) 2009
- LEED Canada for New Construction and Major Renovation (NC) 2009
- LEED Canada for Core and Shell Developments (CS) 2009
- LEED Canada for Commercial Interiors (CI) 1.0
- LEED for Homes
- LEED for Neighbourhoods

Canada's LEED rating system has some minor differences compared to the USGBC's LEED program. One of the differences is that Canadian projects must meet the Minimum Program Requirements (MPRs) which are basic characteristics that a project must possess to be eligible for LEED certification (except for LEED for Homes). As of September 1, 2012, this MPR was adapted from the USGBC's Minimum Program Requirements Supplemental Guidance in order to comply with the context of the Canadian marketplace. Canadian projects must be registered to the CaGBC rating system when the Canadian version is available. However, when the rating system is only available with the USGBC's rating system, such as LEED for Retail, LEED for Healthcare and LEED for school, the project developer may use the US LEED framework to be LEED accredited. It is important to keep in mind that the Canadian LEED program is also constantly growing and improving its framework. This paper

will focus on the USGBC's version of LEED since the Canadian version is an adaptation of United States' version.

1.4 USGBC's LEED rating system

The LEED rating system is organized into five main categories and two bonus categories. There are other additional categories for LEED-Neighbourhood Development and LEED-Home which will not be described in this paper. On top of these categories, every project must meet the prerequisites of each category. This certification system is based on the total points accumulated achieved in the categories mentioned previously. Depending on the total score, a building can have the following levels of certification: certified, silver, gold and platinum. In general, a score of 40-49 points get certified certification, 50-59 points get Silver certification, 60-79 get Gold and 80 points or more proudly get a Platinum certification. For more information, a checklist for the LEED certification process is provided as an example in the appendix section.

2 Literature review

This section describes the previous research studies pertinent to the use of building information modeling to improve the sustainability of projects. It also reports a synthetic analysis of LEED rating system.

2.1 Previous efforts

In the recent decade, there has been a growing use of the BIM capabilities to improve the sustainability and performance of buildings. Wei and Chen [5] integrated BIM simulation and value engineering to study the relationship between energy savings and construction costs during the design process. Ecotect platform was used to analyze energy consumption of the building. After studying cost increase and energy savings, value analysis was used to determine the most optimum design scheme. Khoshdelnezamiha et al. [6] explored the integration of BIM and Malaysian green building index in an attempt to implement green building design. In this regard, Revit green project template was used to address the assessment criteria of green building index. It was urged that the developed model could provide decision makers with an agile assessment platform of green buildings.

According to Al-Sakkaf et al. [7] there was no single way that can be marked as the 'right one' to use particularly in the BIM for heritage buildings.

Hence, it is recommended to develop and validate a heritage building-specific system by tailoring other rating systems to fit the context of heritage buildings. Fulvio et al. [8], [9] presented BIM-based methodology that aimed at establishing a semi-automated sustainability assessment of buildings. In the developed model, the certification process is carried out through common data environment, which can assume four states of archive, shared, published documentation and work in progress. It was highlighted that the developed model could facilitate the sustainability rating process of buildings.

Khanzadi et al. [10] proposed an optimization model to find the best selection of building's' components meanwhile maintaining the sustainability aspects of buildings. In it, non-dominating sorting genetic algorithm was deployed to find the optimum combination of components according to minimization of cost, maximization of energy savings, maximization of recyclable materials and minimization of localization. In this regard, a recyclability index was constructed for the building components based on LEED rating system. Sanhudo et al. [11] introduced BIM-based model for the automated assessment of sustainability aspects of buildings. In their model, a low level of development was considered to deliver an efficient storm water runoff. It was shown that the developed model can calculate the runoff of building sites which can improve storm water runoff management.

Abbasi and Noorzai [12] introduced a multi-objective optimization model to minimize operation and embodied energy of buildings. In this context, a BIM model was constructed to analyze the geometric features and amount of materials in the building. Also, life cycle analysis was performed to analyze the energy demand of the different mateials. Al-Sakkaf & Ahmed [11] stated that over the past four decades, building modeling has taken numerous forms utilizing available technologies and software. Building information modeling has significantly developed with the continuous advancements in the information technology and hardware industries. The evolution of BIM has attracted many researchers to explore its possible applications in modeling buildings and facilities with a humanitarian heritage value. However, researches have not been limited to that, as they later expanded to test the applicability of BIM in progressing the fields of maintenance and rehabilitation, operation and management, and even checking the durability of such buildings against varying circumstances and usability as well. As a result of a deep literature review, this research is developed to provide a critique of the previous studies conducted on the fields of heritage building information modeling (HBIM), the relevant software and equipment used in those studies, as well as case studies and applications used to demonstrate HBIM Capabilities.

Additionally, the current trends of protection and use of heritage buildings and cultural heritage components testifies to an increasing attention of the study of heritage and legacy. The literature review indicates that there many existing rating systems developed to evaluate the performance of buildings from a sustainability point of view. They all based on three pillars; environment, physical, and society. Also, LEED, BREEAM, CASBEE, ITACA, and others are examples of these rating systems. Nevertheless, each of them has its own assessment attributes that originate from its local context. Besides, none of the rating systems proposes a definitive guideline for the decision makers to select the best affordable rehabilitation alternatives, taking into account the sustainability of the buildings. Nevertheless, there is an absence of a comprehensive rating systems that could assess heritage building elements and assist facility managers in their rehabilitation decisions [12].

2.2 Credit categories

The following will briefly describe each of the main categories (United States Green Bulding Council, 2013):

- Sustainable sites: This credit promotes strategies to minimize the impact to the ecosystem, environment and water resources.
- Water efficiency: This credit focuses in promoting efficient usage of water and reducing the potable water consumption.
- Energy and atmosphere: This credit encourages better energy efficient building performances.
- Material and resources: This credit promotes using sustainable building materials and reducing waste.
- Indoor environmental quality: This credit promotes better indoor air quality and access to daylight and views.

Two bonus categories are as follows:

- Innovation in design or in operation: This credit encourages developers to think outside the box and address sustainable building expertise as well as design measures not covered under the LEED framework.

- Regional priority: This credit addresses regional environmental priorities for buildings in different geographic regions.

The weightings process differs from rating systems. For instance, LEED Canada EB:O&M "includes credits related to solid waste management within the building but LEED Canada-NC does not" [13]. Therefore, there is a difference in the portion of environmental footprint addressed depending on the rating system.

2.3 LEED Certification Process

In order to be certified LEED, the project must be identified with the rating system that is best applied to the project. It is very important for a project team to pay attention to additional details on the applicability of the rating system. It is strongly suggested to refer to the LEED Canada Reference Guides for more information. As of September 1, 2012, all Canadian projects must meet the MPRs described previously. The following are general steps for the LEED Certification process:

1) Ensuring that the eligibility of a building for certification;
2) Registering the project with a LEED program with the Green Building Certification Institute (GBCI). Established in 2008, the GBCI was created to support the USGBC to manage LEED building certification and the Professional Accreditation Processes. This institute administers the LEED certification by performing third-party technical reviews and verifications of registered projects. It will help project team to determine whether the project has met the standard set forth by the LEED rating framework;
3) Ensuring and documenting that the project meets the prerequisites of the applicable LEED rating system;
4) Documenting that the project attains at least the minimum number of points to achieve at least the minimum rating, the Certified level;
5) Submitting online to the GBCI the required documentation demonstrating that both the prerequisites and points have been achieved;
6) If necessary, appealing points denied by the GBCI;
7) Receiving final notification from the USGBC or CaGBC that the project has been certified.

Once these steps have been completed and that all certification fees have been paid, the project will receive a plaque with its rating which can be displayed proudly on the building. This is not an easy process since 3000 buildings have been registered since 2006 and only 400 of them is certified LEED [14].

2.4 LEED online

LEED online is an internet based system that allow project documentations to be submitted online. It stores all documentations (LEED information, resources, support) with a very user-friendly interface in one centralized location. This feature allows to user to:
- Upload credit templates;
- Track Credit Interpretation Requests;
- Manage key project details;
- Contact customer service departments;
- Communication with reviewers throughout the design and construction reviews.

It can be notice how LEED online plays an important role for building information modelling.

2.5 A Critic of LEED certification: Advantages and Disadvantages

Although this LEED program is far from being perfect, it does offer many advantages. The following points sum up an article called *The LEED Green Building Certification Program: Spurring Growth in Sustainable Building, Design and Construction in the U.S. and Across the Globe* [2]:
- This program gives initiative and framework for project teams to contribute to a more sustainable future. This voluntary rating system encourages buildings to reduce energy consumptions and water usage.
- There are many studies that show that LEED buildings perform better than non LEED certified buildings. According to the EPA's (Environmental Protection Agency) national benchmarking scale for energy performance, 60% of LEED certified buildings are in the top 15% of the world's most energy efficient buildings. Also, the U.S Department of Energy found that LEED-certified buildings to have 25% lower energy usage compared to the national average. Another study, from the PNC's Bank branches by the University of Notre-Dame, found that the annual utilities cost per employee in a LEED certified building is

675.26$ lower than a non LEED certified building.

- LEED allows developers to building better buildings because the LEED process demonstrates leadership, innovation, environmental stewardship and social responsibility. There are currently 180 000 accredited professional across the globe who holds credential to help building owner in delivering a more efficient and sustainable buildings.
- Materials and water efficiency credits offer tremendous benefits to the environment.
- USGBC has proven that that a healthy environment and a strong economy can go hand in hand since the LEED program encourages companies to develop products and services that support better buildings and communities. LEED certified building reduces energy, water and resource consumptions, creates jobs, saves money and drives innovation.

Despite the advantages of LEED, this program also has its downsides. Since LEED is a point based system, some designers may only focus on meeting the requirements of LEED and ignore innovation of the project. A famous Canadian architect called Frank Gehry once said that "a lot of LEED is given for bogus stuff". Some designers install systems that have no particular functions just to acquire LEED credits. A good example is Concordia's John Molson School of Business. As illustrated in the figure below, the windows in the building are installed with handle cranks.

Fig.2: Window view from the John Molson School of Business building. Picture is taken by Wilson Wong.

There are no particular functions in installing these handle cranks since it is considered very dangerous

if these windows were ever opened. It can be hypothesized that these handle crank were installed to satisfy the IEQc6.2 Thermal Comfort criteria of the LEED certification. In the Indoor Environmental Quality category, it is stated that all multi-occupant spaces must have at least one occupant comfort control. A common way to earn this credit is by installing operable windows. This enables the applicant for LEED to receive 1 credit point. Although the LEED program is not perfect, it does offer a very good framework that encourages people to build more sustainable buildings. In addition, the following are focused on the sustainable buildings benefits: Improved Indoor Environment: Quality of Life; Saving Water: Reduce, Reuse, Replenish; Enhanced Health: Eco-Friendly For Life; Reducing The Strain: Shared Resources, Increased Efficiency; Reduced Operational Cost and Maintenance: Traditional vs. Green; Energy-Efficient: Non-Renewable vs. Natural Resources; Carbon Footprint Reduction: Saving The Planet One Step At A Time; Keep It Clean: Protecting Our Ecosystem; Efficient Material: Minimal Use For Maximum Impact; and Durability For The Green Homeowner: Built To Last. Therefore, this is why this program is constantly growing, evolving and pushing limits to a more sustainable future.

3 Methodology

The methodology of this research has been divided into seven subsections as the following.

3.1 Integrating LEED documentation requirement within BIM practices

In this section, a general outlook of the current BIM users with regard of sustainable designs and LEED certification process will be provided, and some currently used practices integrating BIM and LEED application will also be presented and analysed.

3.2 Current state of integrating BIM into LEED certification process

One of the most challenging parts of following the sustainable practices promoted under USGBC and CAGBC's LEED rating systems is the required documentation from the design professionals in order to get the building certified under the appropriate rating system. Not only the AEC (Architecture, Engineering and Construction) professionals working on the project will have to submit the normal required documentation to project

stakeholders for approval, but they also have to prepare the appropriate documentations for LEED certification purposes. As previously explained, even if LEED Online has been used extensively for documentation submittals nowadays, a successful project still requires far-reaching documentations in order to be LEED certified.

Ever since LEED has gotten popular with the general public and AEC industries, businesses and BIM developers perceived this as an opportunity and started to develop functionalities in the existing software package aimed at designers who will design building performance in energy efficiency, indoor air quality and other benchmarks. For example, there have been new development for commercially available software packages, including Autodesk Green Building Studio® (conceptual energy simulation, daylight and water consumption calculation), Integrated Environmental Solutions – Virtual Environment's VE Navigator (for complete LEED credits analysis, including energy modeling) and Bentley AECOSim (for baseline LEED energy simulation) and other solutions that are being developed by various governmental and semi-public agencies. Businesses that dedicated to green building and sustainable designs are flourishing. Just until 2011, USGBC papered of having 61718 registered LEED APs with various specialties in USA and Canada [5]. In "Leveraging Cloud-BIM for LEED automation" [6], the authors have identified the following process diagram between the construction process, business, technology and stakeholder. In their article, it is stated that empirical experiences and best practices push the advancement of green information and communication technology to facilitate the transition, which necessities innovation of the business process.
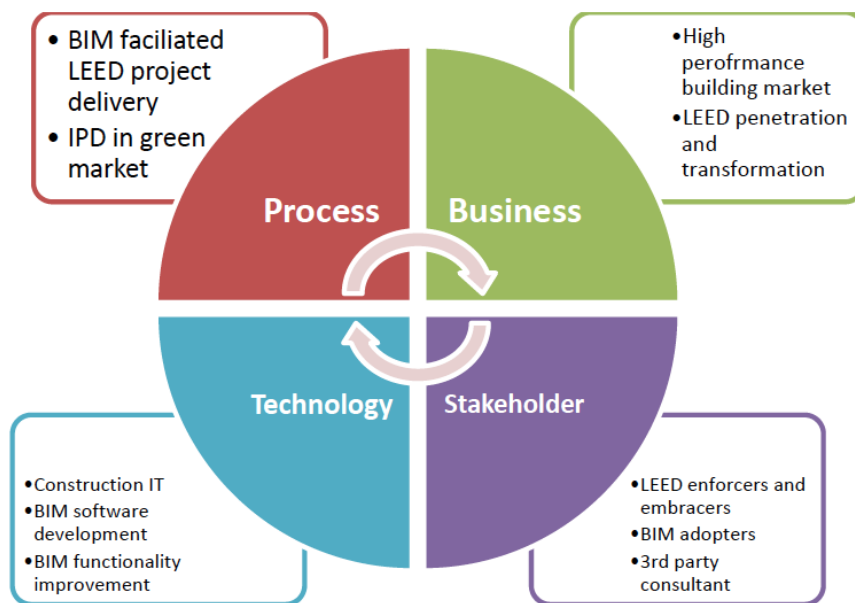

Fig.3: Integrate BIM and LEED - Loop of Interaction.

Using BIM software and tools available to AEC professionals could potentially be the magic solution that will save time, energy and financial resources from AEC firms and project owners. Due to its highly automated and parametric nature, BIM offers huge potentials for AEC professionals, starting from the early stage of the design phase all the way till the end of construction phase. BIM offers an unprecedented cooperating opportunity for AEC professionals from all disciplines, as well as other stakeholder of any construction projects, to get involved with the construction project on regular and informed basis.

However, the adoption rate of using BIM for sustainable designs, particularly for LEED, is not as widespread as one may hope. According to a survey conducted by McGraw-Hill Construction, Green BIM, How Building Information Modeling is

contributing to Green Design and Construction, only 17% of firms that are practicing Green BIM papered to have use at least half of the potential BIM can offer for green projects (Green BIM: How Building Information Modelling is contributing to Green Design and Construction). Within the same paper, the most identified trigger for BIM adoption is not the improvement of productivity, but by owner's request (Green BIM: How Building Information Modelling is contributing to Green Design and Construction).

Although it is always expected that adoption to new technology will always be delayed by various factors, encouraging signs are showing in the market place. Still within McGraw-Hill paper, 78% of BIM users who do not use BIM for green projects are expected to be doing so within 3 years, and 48% of all BIM users are relatively new learners (with experience under 2 years) (Green BIM: How Building Information Modelling is contributing to Green Design and Construction).

Specifically for LEED projects, the McGraw-Hill paper shows a very important trend. About 42% of the "Green" BIM users consider that BIM technology is with "medium" and "high" usefulness in its current form, and about 38% find that the current technology is of "low" usefulness (Green BIM: How Building Information Modelling is contributing to Green Design and Construction). But at the same time, when questioned about the automation between BIM and LEED papering systems implanted within their firms, only 24% of "Green" BIM users answered with high or medium level of automation (Green BIM: How Building Information Modelling is contributing to Green Design and Construction). The main challenges identified for BIM adoption for LEED certification purposes are the lack of tools, missing functionality and complexity of the model used. While one might see this as a generally pessimistic portrait of BIM integration with sustainable designs, but the identified challenges and concerns are all due to lack of automation tools and processes to improve productivity of AEC professional. Specifically for LEED certification process, the challenge is to develop new processes within BIM to facilitate the

documentation gathering process. Ideally, this process could be automated and if desired, transmits information directly to LEED online system. However, at the current stage of development, not all of this is possible. But some commercially available alternatives or best practices are available. 3 examples of practices documented will be presented in the following sections.

3.3 LEED credit documentation requirements

LEED certification system is a very complex system. In order to pursue LEED certification, credits must be earned by submitting the appropriate documentations to GBCI. However, not all credits need quantitative analysis. Credits can be separated into 2 categories according to their documentation requirement: credits requiring qualitative analysis and credits requiring quantitative analysis and credits requiring quantitative. For qualitative credits, no numerical analysis is necessary, therefore the documentation limits to textual references, which cannot easily generated by BIM automated process. However, not all credits requiring quantitative analysis need numerical analysis, sometimes graphic analysis are preferred *(for example: SSc4.1 Public Transit Access)*. The following table is tabulated based on LEED New Construction system, which separates all credits into the following qualitative, quantitative with analysis and quantitative with graphs or other documentations.

Table 1: Credits for LEED New Construction according to documentation requirement.

Qualitative	Quantitative with analysis	Quantitative (other methods)
SS P1 Construction activity pollution prevention	SSc8 Light pollution reduction	SSc1 Site selection
	WEc2 Innovative waste water technologies	SSc2 development density and community connectivity
SSc3 brownfield redevelopment	WEc3.1 and WEc3.2 Water use reduction	SSc4.1 Public transportation access
SSc4.3 Low-emitting and fuel-efficient vehicles	EAp2 Minimum energy performance	SSc4.2 Bicycle storage and changing rooms
SSc6.2 Stormwater quality control	EAc1 Optimize energy performance	SSc4.4 Parking capacity
EAp1 Fundamental building systems commissioning	EAc2 Renewable energy	SSc5.1 Protect or restore habitat
EAp3 Fundamental refrigerant management	EAc6 Green power	SSc5.2 Maximize open space
EAc3 Enhanced commissioning	MRc1.1 and MRc1.2 Building reuse — existing walls, floors and roof	SSc6.1 Stormwater quantity control
EAc4 Enhanced refrigerant management	MRc1.3 Building reuse — existing interior nonstructural elements	SSc7.1 Reduce heat island effect — nonroof
MRc2.1 and MRc2.2 Construction waste management	MRc3.1 and MRC3.2 Materials reuse	SSc7.2 Reduce heat island effect — roof
IEQp1 Minimum indoor air quality (IAQ) performance	MRc4.1 and MRc4.2 Recycled content	WEc1.1 and WEc1.2 Water efficient landscape
IEQc3.1 Construction IAQ MGT plan — during construction	MRc5.1 and MRc5.2 Regional materials	EAc5 Measurement and verification
IEQc3.2 Construction IAQ MGT plan — before occupancy	MRc6 Rapidly renewable materials	MRp1 Storage and collection of recyclables
IEQc5 Indoor chemical and pollutant source control	MRc7 Certified wood	IEQp2 Environmental tobacco smoke (ETS) control
IDc1 Innovation in design	IEQc4.1 Low-emitting materials — adhesives and sealants	IEQc1 Outdoor air delivering monitoring
IDc2 LEED accredited professional	IEQc4.2 Low-emitting materials — paints and coatings	IEQc2 Increase ventilation
	IEQc4.3 Low-emitting materials — carpet systems	IEQc6.1 Controllability of systems — lighting
	IEQc4.4 Low-emitting materials — composite wood and agrifiber	IEQc6.2 Controllability of systems — thermal comfort
	IEQc7.1 Thermal comfort — design	IEQc7.2 Thermal comfort — verification
	IEQc8.1 Daylight and views — Daylight	

As the McGraw-Hill survey identified and this table shows, the main challenges facing AEC professionals using BIM to pursue LEED certification is that the process is very long and complex, if no proper tools are provided, the BIM software or processes can be long and arduous. Therefore it is essential to establish workflows that will benefit AEC and project stakeholders that are using BIM technology to apply for LEED rating

systems, making it financially attractive to owners

3.4 Current practiced and accepted LEED project certification workflows

There are lots of advantages using BIM software to document LEED credits. For credits requiring graphic documentations such as plans, sections and elevations, due to BIM software's' parametric change technology, for which allows user to coordinates changes and maintain consistency of the model at all time. Other credits that need products information (For example: WE C3.1 Water Use reduction) can also be easily documented using BIM by simply providing scheduling information, if properly established at the beginning of the projects. Also, credits that require "phasing", i.e. time information (MRc1.1: Building Reuse) could also be potentially extracted using BIM software, if the model is properly designed with time-related information stored. What are lacking in current BIM software development are the analysis tools available within the program itself. The most popular commercial BIM for software, such as Autodesk Revit®, Graph iSOFT ArchiCAD® and Bentley's Bentley Architecture, all have little or none ASHARE compliant energy modelling capabilities, for which Energy efficiency can represent up to 35 points. Due to the importance of those energy performance points, workflow processes are made in order to efficiently extracting information from BIM software and process through for LEED documentations. However, some considerations have

to be taken into account while preparing this kind of BIM models:

- Properly position 2D bounding elements and openings.
- 2D boundaries need to be properly connected and bounded in order to perform energy analysis in various tools. Unnecessary connections should be trimmed and reduced in order to reduce the size and complexity of the BIM model.
- Properly adjust volume and area settings.
- Volume and area settings should be adjusted according to each software specific requirement. However, general rules dictate that the boundary locations, volume and area calculation methods, limits are to be set according to software requirements.

and AEC professionals.

- Select necessary building elements will be used in analysis.
- Not all building elements are needed in some of the numerical analysis. Elements such as furniture, landscaping elements and other components can be turned off during the simulation. However, some elements are essential and needed to be kept, such as shading devices, windows, ceilings, curtain walls, etc. Simplification is the key to make a successful analytical model out of the same design model.

In the following sections, 3 possible workflows are presented and discussed, using in program plug-ins, 3rd party software independently of BIM and Cloud Computing with BIM and LEED automation.

3.5 In program plug-in

One of the most convenient facts about BIM software is that plug-ins can be easily developed by experiences programmers for various needs. In pursue of LEED certification, some plug-ins for various software were developed in order to increase the productivity of AEC professionals and decrease the time spent on doing LEED certification related processes. One group of researchers from California State University Long Beach has developed a complex plug-in to assess any projects potential for LEED certification. In their journal article to the Open Construction and Building Technology Journal, a plug-in was developed for Autodesk Revit in order to evaluate a project's maximum point under LEED New Construction Rating system. The researchers established, before undertaking the LEED evaluation of their BIM model, basic parameters qualified as "Green Building Properties" as a mean to quantify information of qualitative nature, such as percentage of recycled content within a material. This work is done within Revit software and is quite labour intensive.

Then, the researchers established a sustainability assessment frame work using IDEF0 model (Integrated Definition for Functioning Model), for which inputs are analyzed through a set of functions with various controls and mechanisms, then outputting an assessment based on those results (Nguyen, Shehab, & Gao, 2010) [7]. Following figure explains the framework of their plug-in.
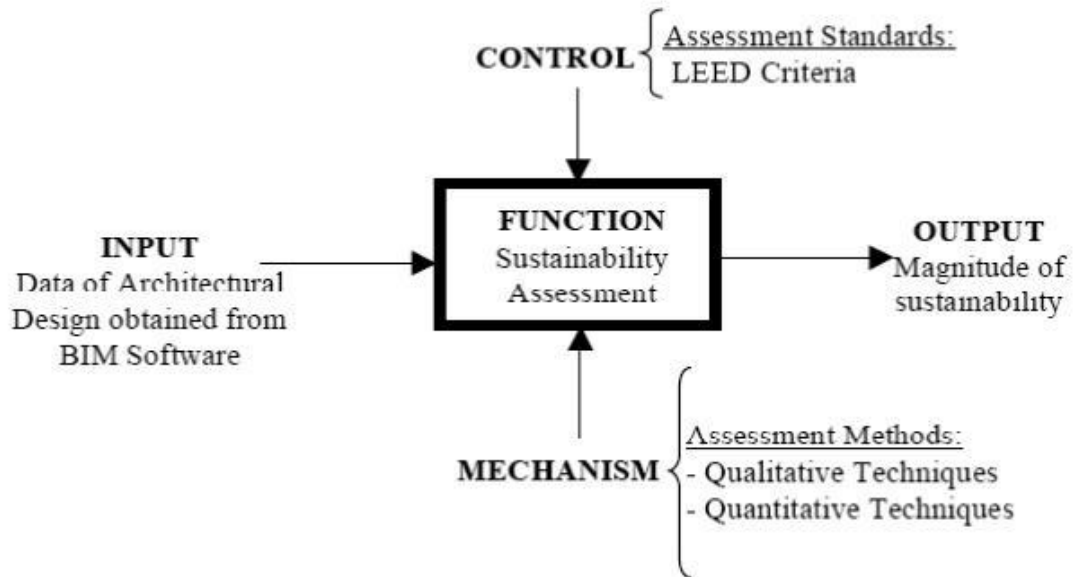
Fig.4: The sustainability assessment framework.

The results of this assessment tool, if all data entered correctly in their respective parameters, should indicate how the project can fair within the LEED New Construction rating system. An example output is also attached.

Fig.5: Example output of the assessment tool.

However, the presented tool lacks the ability to provide detailed analysis results for various key numerical analyses, as well as the ability to generate necessary LEED online submittal files. While the plug-ins offers to be the most convenient tool for BIM users as an assessment tool, there is still a very long way to go before it can compete with 3rd party software and other methods.

3.6 3rd Party Software

Using 3rd party software that is independent from the BIM design software for some LEED credit analysis is the most popular way to prepare for LEED documentations right now among AEC professionals. Especially for credits that require special numerical analysis, such as WEc3.1 and 3.2 for portable water use reduction, EAp2 and EAc1 for Energy Performance Optimization, IEQc7.1 (thermal comfort-design) and IEQc8.1 (daylight views and daylight). For these credits, detailed numerical analysis is required, sometimes complex simulation models have to be made for energy and daylight calculations. The current workflow that most of AEC using BIM for LEED certification is to model and program the building information model by using BIM specific software (Autodesk Revit®, Graph iSOFT ArchiCAD®), then repackage the design model to an analytical model that can be exported to specialized evaluation software, doing an energy analysis or daylight analysis by using the 3rd party software. A common file interface was developed by Autodesk in order to facilitate this file transfer process; gbXML is widely used and accepted by AEC professionals.

The research from Salman Azhar, *Building information modeling for sustainable design and LEED rating system*, dealt with this kind of process using Autodesk Revit and IES' Virtual Environment. In this research, the author has used Revit to build the case study model, then packaging the analytical model using interface provided by Revit and exported it through gbXML. Then the gbXML file is imported back into Virtual Environment, in order to complete LEED specific analysis and some LEED submittal documentations. The whole process is illustrated below in the graphic [8].

Fig.6: Key steps for sustainable analysis and LEED documentation using BIM and 3rd party software.

Another method is provided by Autodesk, using similar approach, but focused more on the required energy analysis using publicly available software. In the Technical Note: Energy Analysis Workflows for Sustainability, a process is described in details for AEC professionals using Autodesk Revit to pursue LEED and other green rating systems.

BIM users will still have to make the design model in Autodesk Revit, but then instead of porting the design model out using gbXML, users are directed to use an online application provided by Autodesk called GreenStudio, which offers simple conceptual energy analysis and lighting analysis. Then users can port out an eQuest specific format directly from GreenStudio, in order to pursue further energy analysis using eQuest. The following graphic is provided to illustrate this process (Technical Note: Energy Analysis Workflows for Sustainability, Autodesk).
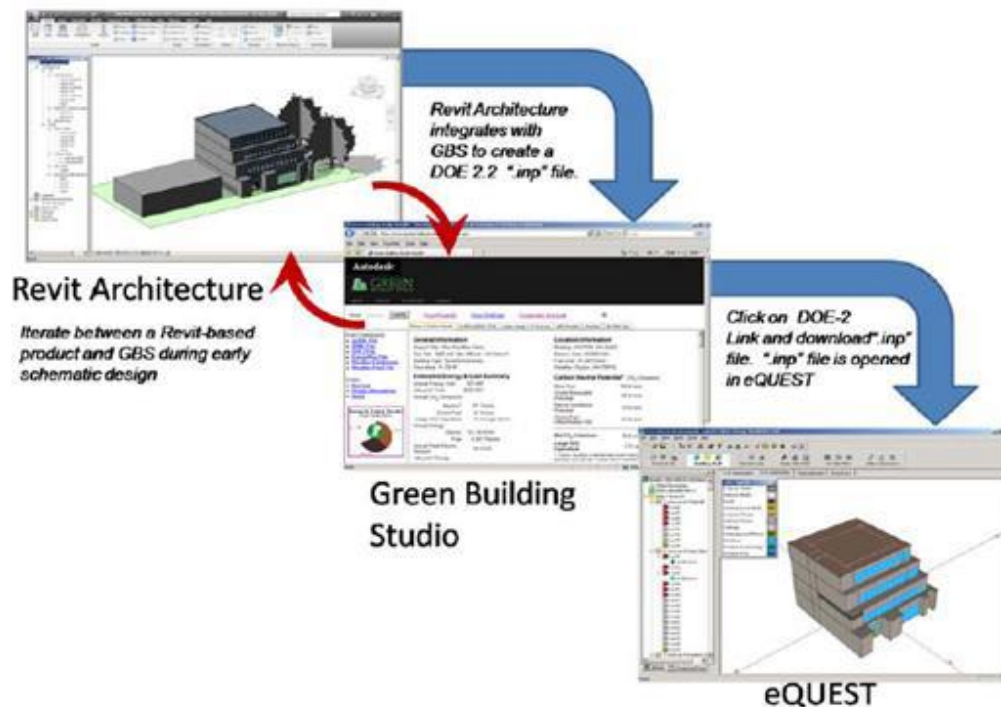
Fig.7: Process describing LEED sustainable analysis using Revit, GreenStudio and eQuest.

The most complicated and used analysis for LEED certification process is the Energy Performance evaluation. Not only it has the most point potential, but also it is the most complicated one to us. For 3rd party evaluation software, CaGBC has an list with approved modeling software to be used for the EAp2 and EAc1 energy performance analysis (Canada Green Building Council, 2013) [9], contrarily to USGBC's policy for not providing particular software but rather criteria of acceptance. The following software accepted for Energy Evaluation: Trane TRACE, Carrier HAP and eQUEST. Although this process can be long and labour intensive, it is the most adopted solution for AEC professionals using BIM for LEED. Some software has more analysis than another; it is up to each BIM user to discover the appropriate software/process for their particular project.

3.7 Cloud-computing with BIM and LEED automation

Cloud computing is another promising technology that could potentially revolutionize the construction design and BIM usage. According to National Institute of Standards and Technology, Cloud-Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g.,

networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [15]. Within this framework, 3 types of service models exist now, software as a service, platform as a service or infrastructure as a service can be deployed over private cloud, community cloud, public cloud or hybrid cloud [15].

AEC projects, especially BIM based projects could benefit from the availability of online shared services, such as sharing the BIM model across the AEC teams participating in any BIM projects, or other server based applications that allows user to automate part of their workflow, either in design or in documentation preparation for LEED certification. Current development of BIM cloud technology follows this trend, cloud based BIM application and BIM servers are being developed in order to satisfy the needs of AEC professionals [16].

Ghasan Alfalah, Abobakr Al-Sakkaf,
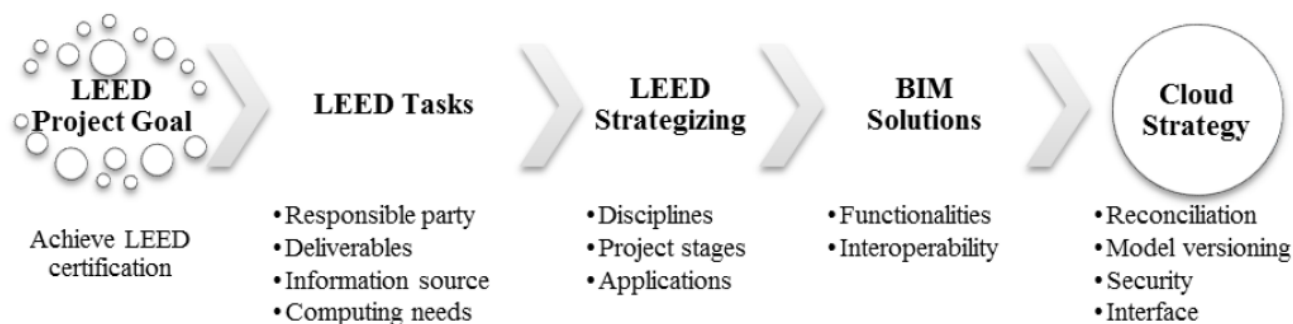Eslam Mohammed Abdelkader

Fig.8: Framework development process.

In the article *Leveraging Cloud-BIM for LEED automation*, one particular framework is proposed by the authors for automate the documentation and design process of LEED projects using Cloud-BIM technologies. The proposed strategy is to establish a BIM enabled Cloud server, with various necessary BIM applications installed, along with the ability of remote access to BIM model files and data acquisition software on construction site, combined with the possibility of using automated LEED online submittal forms to create an automatic workflow for documentations preparation of LEED rating system. There will be a *central multicore BIM server* that is used to store and manage central BIM models and host project data, documentation generated and enable information exchange between *LEED analysis server*, which provides online application for necessary LEED analysis, and *BIM authoring* server, which handles model creation using BIM software. There could also be a *Field Cloud*, serving as data acquisition server or on-site document consultation server. The last component of the whole process is the *LEED automation Cloud*, specializing in LEED certification process with emphasis on streamlining the automated LEED documentation generation, managing LEED Online templates submission and tracking certification status [16]. The whole process is illustrated below in Figure 9.
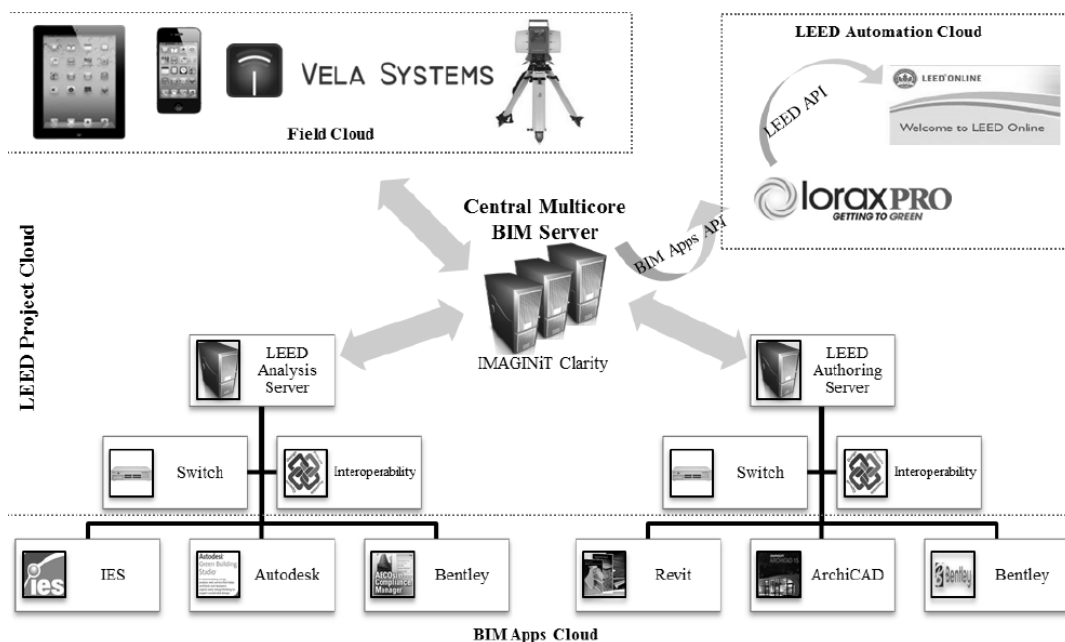
Fig.9: Framework of cloud-BIM leveraged BIM automation.

Depending on the complexity of the project, the AEC professionals have to choose the most appropriate workflow to use. A less complex project can obviously be documented using 3rd party evaluation software, but an investment into a cloud-BIM server is justified if the projects handled exceed certain volumes. Of course, future development could lower the cost of cloud-BIM and making it feasible even for smaller projects.

4 Case Study

4.1 Shanghai Tower (China)

Shanghai Tower is considered as one of the tallest buildings in China. It is designed to represent China's past, present and future in its first super-tall district in Shanghai. The designer of the tower takes has set to achieve sustainable designs as well as to make the building to project the vision of the future onto the present. In the early stage in the design process, the owner, Shanghai Tower Construction & Development Co., Ltd, and the design architect, Gensler, realized that BIM will help them to control and integrate design, due to the complexity of the structure and coordination of an international team, on top of achieving their sustainable goals [13].
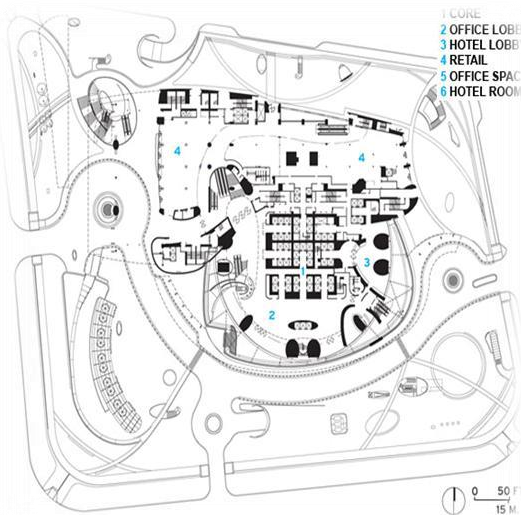

Fig.10: Shanghai Tower.

The tower has an exterior cylindrical shape which divides its elevations into nine sections. These nine cylindrical sections are stacked on top of each other and cover the entire building. Behind the exterior cover, the structure is enclosed by a triangular exterior curtain wall. This curtain wall makes it more attractive with a high tech touch, on top of adding natural ventilation to it. In addition, the designer rotates the building while creating a spiral form out of it. The spiral form makes the building reduces the wind load and helps to gather the
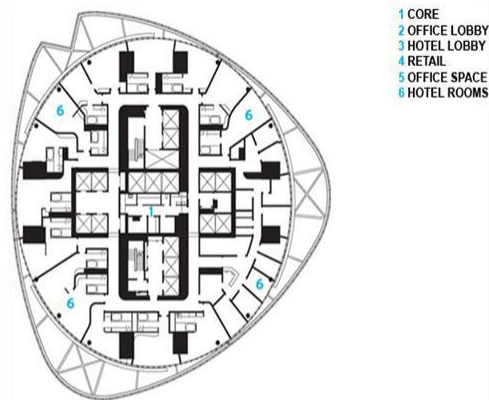
rainwater to achieve the most important feature in sustainability, which is water use reduction (Green BIM: How Building Information Modeling is Contributing to Green Design and Construction, 2010).
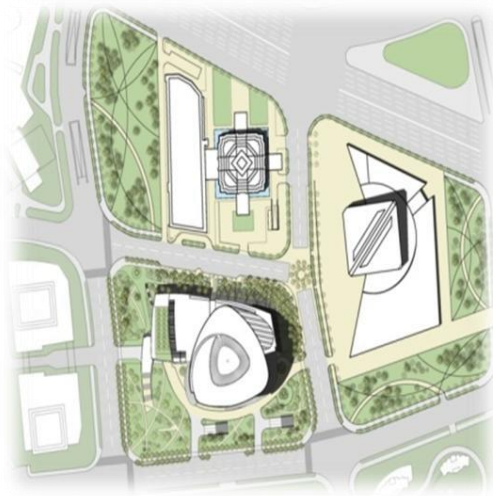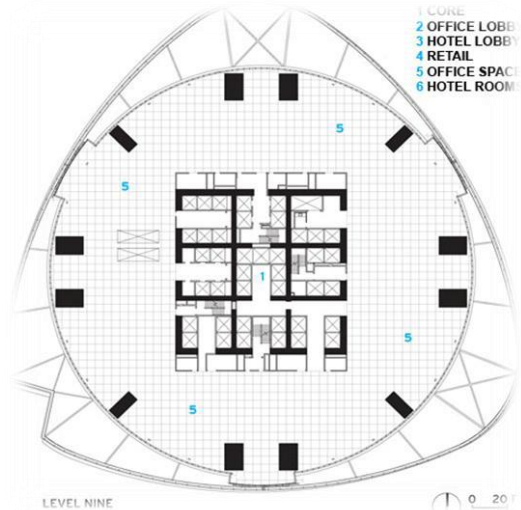

a)

b)

c)

d)

Fig.11: Tower. Architectural plans for Shanghai Tower.

Michael Concannon, production coordinator at Gensler, stated that they have to use the advantages of BIM for Shanghai Tower because using BIM will let they know and understand very well the entire scope of the project. He also added when they designed the exterior skin to cover all building's elevations, they have to do it in 3 dimensions to understand all details about the double façade, such as how will the curtain wall enclosure and the exterior skin interact with each other and how the design group will design the two façade with each other. BIM helped them to absorb all of these complex details. With the help of BIM, the designer believes that Gensler was able to do more complex work, because of BIM makes the connections very easy between all AEC professionals involved in this work and make the work go smoothly and faster throughout the construction and design process (Green BIM: How Building Information Modeling is Contributing to Green Design and Construction, 2010).

Ghasan Alfalah, Abobakr Al-Sakkaf,
Eslam Mohammed Abdelkader

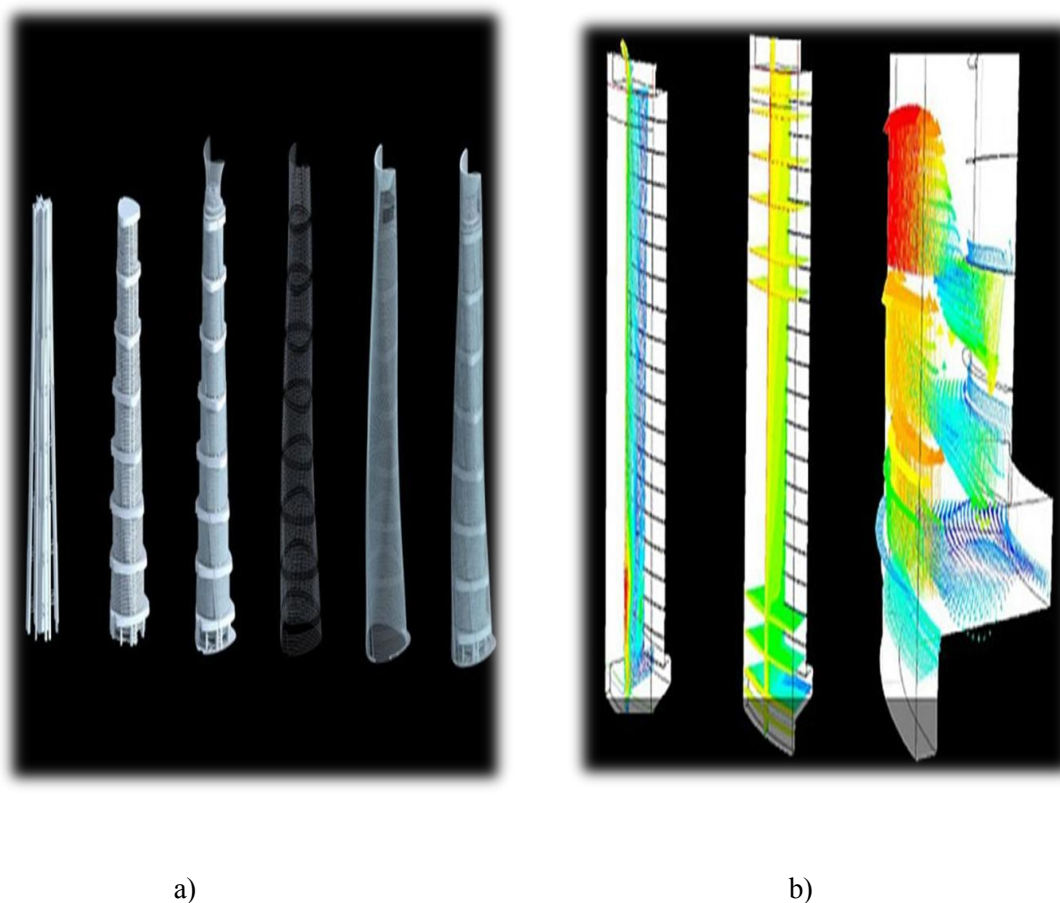a)   b)

Fig12: Innovative facade modeling for Shanghai Tower.

There is another BIM advantage used to achieve sustainable objectives in this project. BIM gives each AEC professional working in this project to share his or her sustainable vision and strategy in order to achieve the design objectives. By using BIM one can design a model and discuss one's vision with the client, the other AEC professionals, the contractor about the strategies used in order to meet the green and set out to meet as many as LEED requirements agreed before. With BIM model, all team members can be fully visualize and understand other's vision by using visualization tools. Other tools help all members of this project to coordinate a much leaner process. Without using BIM modeling in an international work team, all heavy drawings have to be shipped and send one and another in different countries and the team members have to discuss the drawing and send them back to its point of origin. In order to save cost and time, on this project, digital works replaced this cumbersome process. Moreover, this practice reduces the carbon footprint of this project. Both the design team and the owner also credit BIM with increasing the owner's participation into the project. One of the most important things that make BIM important in this project is that it allows all stakeholders involved to work with the design and construction team to plan, coordinate and control all aspects of the work. Using BIM is not restrict only during the design/construction process, but also in the tower's daily operations after construction completed, coordinating and optimizing the operation scheme, equipment management, real estate management and emergency management. In this project the BIM played an important role to achieve high LEED certification and Three Star (the Chinese green building certification program) ratings. BIM did not only help to create a sustainable, super tall building, but it also helped to achieve significant cost savings in many aspects of design, construction and building operation of this project [13].
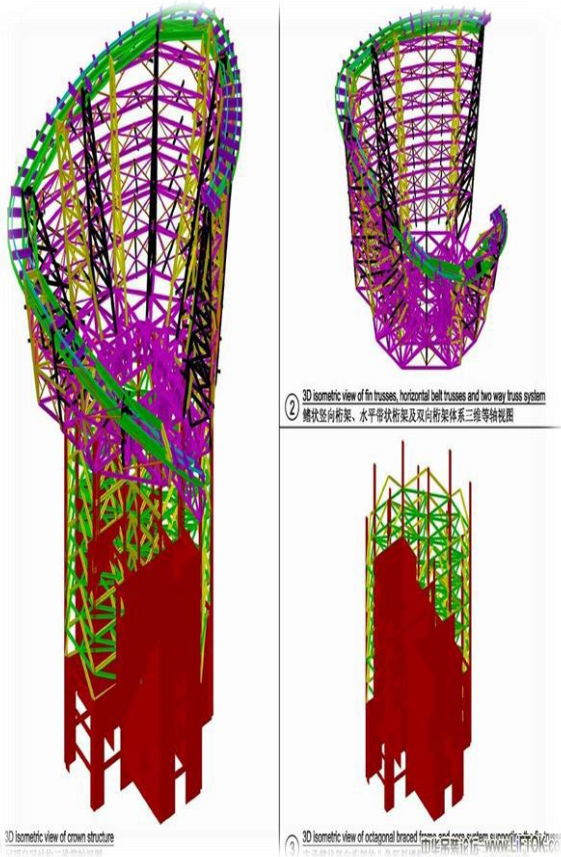
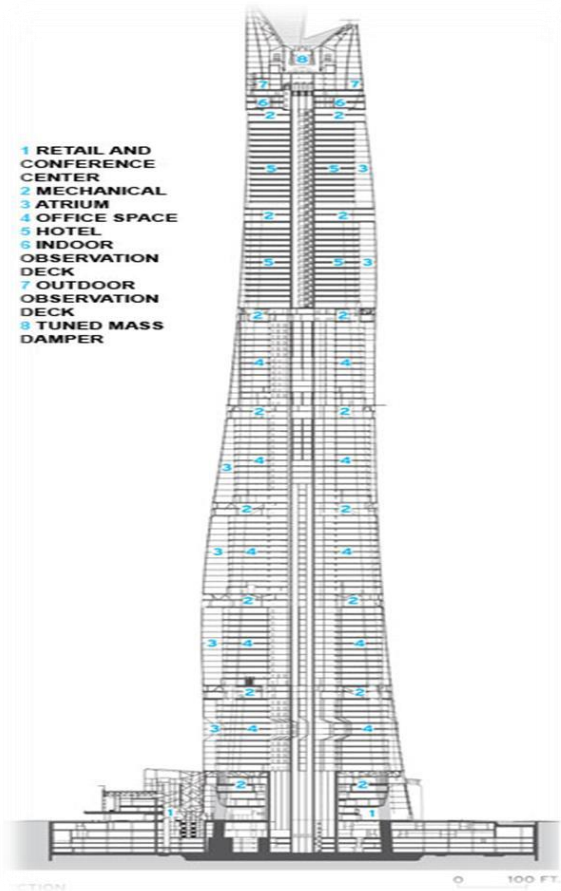Fig.13: Structure Details and Project Section.

Fig.14: Structure Details and Project Section.

Using BIM techniques facilitated the creation of this complex shape and structure, by making them easy to understand for all AEC professionals involved, including harvesting rainwater and using wind turbines. The use BIM has a lot of impacts in this project, including to reducing the materials that AEC professionals used in this project. BIM technology allowed team work to design the most efficient structural frame of the tower, by testing and analysing the impact of the spiral form and rotation of the tower as shown in Figure 15. This shape helps the design team to develop the current exterior configuration, which reduces the wind load by about 24%. Reduction by spiral form makes the work team use less steel but in the same time they still meet the stiffness and toughness. Also, the shape helps them to reduce energy consumption and save energy as well as material, since steel is a particularly energy-intensive product. Figure 15 shows the cost savings are also significant: because each reduction of approximately 5% is equivalent to approximately USD $ 12 million in savings. The tower design also uses 14% less glass than a square building with the same area (Green BIM: How Building Information Modeling is contributing to Green Design and Construction, 2010).
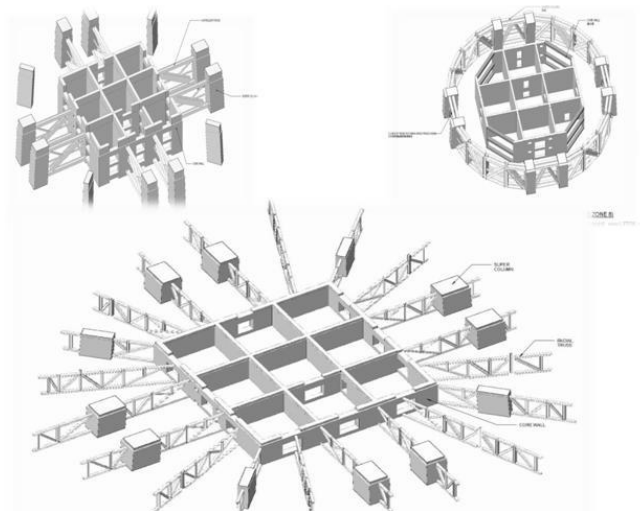

Fig.15: Radial Truss [3].

BIM also involves suppliers into the design process earlier on, because they can use BIM models to estimate the materials that they need. These materials saved will create value for the owner by allowing the suppliers to minimize over purchasing and on-site modifications [13].

BIM played an important role in this project and assisted the AEC professionals involved to achieve their significant energy reduction goals. Alternatively, the BIM model helps the design team with specific, quantitative feedback on building energy performance. Using BIM helps the team work to lessen concerns about not hitting the metrics for targeted LEED points (Green BIM: How Building Information Modeling is contributing to Green Design and Construction, 2010).

4.2 The San Francisco Public Utilities Commission Headquarters (USA)

In order to achieve the LEED certification for this project, AEC professionals have to get as much as possible natural daylighting, not only because it will reduce energy, but also because of its beneficial effects to the occupants. As a result, BIM modeling is considered as a very suitable tool to achieve the set objectives, due to its efficiency for lighting analysis. AEC professionals who want to use BIM to achieve sustainable design and pursue LEED certification must focus on lighting and daylighting analysis with BIM and BIM-related tools. For example, BIM tools provide AEC professionals with a good opportunity to make their designs more effective, robust and efficient, because BIM tools can provide more informed choices regarding a building's performance. In addition, BIM will also be helpful with any suggested changes or modifications by any team member, because AEC professionals can do it easily and show how the changes will act with building and if the changes have any impact on the project's sustainability. BIM will help AEC professionals to determine if removing any daylighting features will affect the overall lighting and if artificial lighting is necessary, on top of determining the energy consumptions associated with this action as shown in Figure 16. This will help to evaluate LEED certification possibilities of the project, based on one or some specific design issues [17].

Fig16: The majority of the south facade has fixed shading devices protruding from its high performance glass skin. Automated exterior blinds shade the upper most levels [18].

Utilities Commission project is considered as a good example to show how the AEC professionals get benefits from BIM in daylighting analysis. The designed team used Google Sketch-Up in their daylighting modeling, and then they brought their result that they got them from Google Sketch-Up into Revit. The designers achieve LEED Platinum certification from the United States Green Building Council (USGBC) and they got it in 2012 as shown in Figure 17.

Ghasan Alfalah, Abobakr Al-Sakkaf,
Eslam Mohammed Abdelkader

a)   b)

Fig.17: Architectural plans.

By using BIM features the design team achieved their sustainable goals, by providing on-site clean energy generation through photovoltaic panels, by making 100 percent of waste water treated on site, by using low flow toilets, by increasing 45 percent daylight harvesting than baseline and by reducing 55 percent of energy consumption, which translates into 32 percent less electricity demand from the main power grid as shown in Figure 18.

Fig.18: 3D BIM model.

Ghasan Alfalah, Abobakr Al-Sakkaf,
Eslam Mohammed Abdelkader

While BIM tools help in daylighting analysis and let the AEC professionals involved to improve the communication process with other team members, BIM has also helped them to push their creativity further and make their designs more attractive and distinguished. This creativity has happened because the AEC spent less time inputting data and more time to invest in actual design. BIM tools allow the AEC professionals to make a lot of experimentation on their designs and let them see the result of that. These experimentations that professionals make it will help them to get new ideas because they could evaluate the impacts of their ideas in less time as shown in Figure 19.

Because of Complexities of the project's electrical work, BIM modeling is very effective to understand how all systems throughout the buildings integrate, such as emergency power, lighting, dimming/control, Fire Alarm and security, low-voltage telecommunications, fiber optic data cables

and the parking garage systems interact with each other. In this cause, the Building Information Modeling (BIM) department generated a state-of-the-art 3D model to plan and coordinate all efforts in pre-construction stage with other contractors. In addition, BIM led the design teams to think out of the box and for introducing them to specialty mechanical smoke control system and sound-masking technology through subcontractors involvement [18].

Fig.19: Completed view of the building's wind turbine helping to create an energy-efficient setting for SFPUC staff.

5 Conclusion

In the light of emerging trend of sustainable construction in the recent few years, this research introduces a framework that makes the full use of green design concepts in an attempt to improve sustainable building practices. In this regard, this research analyzes LEED rating system listing its credit categories, certification process, merits and demerits. It also exploits the use of building information modeling to improve energy efficiency of structures. Two case studies are investigated in detail to test the efficacy of the developed BIM-

based model. In the first case study, results evinced that the BIM-based design could reduce wind loads and increase energy savings by 24% and 5%, respectively. In the second case study, it was illustrated that the developed model could lower energy consumption and increase daylight harvesting by 32% and 45%, respectively. It is expected that the developed framework could aid decision makers in experimenting different practices and alternatives that could maintain green design solutions.

The main contribution of the developed model is studying the implementation of building to improve LEED rating of buildings through adapting the design of two case studies in China and United States of America. Future research encompasses integrating building information modeling and some artificial intelligence tools like machine learning models and deep learning models to emulate the influential factors on LEED-certified buildings. Also, meta-heuristics can be hybridized with building information modeling for the sake of optimum selection of materials in attempt to enhance LEED rating of buildings.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Ghasan Alfalah analyzed the findings and the results of the models and aided in writing the article. Abobakr Al-Sakkaf developed the methodology and concept and aided in writing the article. Eslam Mohammed Abdelkader aided in developing the methodology and concept and writing the article.