

**Building Information Modeling Supporting LEED Sustainability
Certification**

– Streamlining the Required Documentation with BIM Tools

**BY
DANDAN LI**

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Supervisors:

Dr. Wolfram Trinius, Ingenieurbüro Trinius GmbH
Prof. Peter Braun, HafenCity University Hamburg

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Abstract

Being used as the reference either for architectural design or project certification, green building certification systems help the buildings achieve better performance in energy, water, and material consumption, thus causing fewer impacts to the environment. This thesis describes the effort of applying Building Information Modeling (BIM) concept to the process of generating LEED required documentation.

Streamlining the LEED required documentation is a critical, but often difficult step in certification process. By researching on the BIM functionality and LEED certification system, a draft integration framework is first generated, figuring out potential categories and credits in LEED to be integrated with BIM. The contents and requirements of each above credit are described, as well as the process of how to use BIM modeling tool and analysis tool to support the documentation.

To verify the integration framework, and to identify the gaps in the framework where currently no existing functionality is available for compliance of certain credits, a case study is done to check the listed credits one by one. Besides addressing the workflow, challenges and obstacles are explained as well. In the end, the LEED credits with higher “BIMability” are figured out.

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List of Abbreviations

AP	Acidification Potential
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineer
ASE	Annual Sunlight Exposure
BIM	Building Information Model, Building Information Modeling
BREEAM	BRE Environmental Assessment Method
CBE	Center for the Build Environment
CFD	Computational Fluid Dynamics
DGNB	German Sustainable Building Council
EA	Energy and Atmosphere
EP	Eutrophication Potential
EPD	Environmental Product Declaration
GBS	Green Building Studio
gbXML	Green Building XML schema
GUID	Globally Unique Identifiers
GWP	Global Warming Potential
HQE	High Quality Environmental standard
HVAC	Heating, Ventilation and Air Conditioning
IDM	Information Delivery Manual
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IPD	Integrated Project Delivery

ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LEED BD+C	LEED Building Design and Construction
MR	Material and Resources
NIBS	National Institute of Building Science
OPD	Ozone Depletion Potential
PMV	Predicted mean vote
POCP	Photochemical Ozone Creation Potential
PPD	Predicted percentage of dissatisfied
sDA	Spatial Daylight Autonomy
USGBC	U.S. Green Building Council
WE	Water Efficiency

Chapter 1. Research background and literature review

1.1 Background of green building certification

Starting in the 1970s in the U.S., the green building movements dates back to various approaches against energy crisis at that time. Active and passive strategies were created to achieve energy saving, which plays nowadays a critical role in the holistic approach that also considers other environmental impacts relating to sustainability (Howard, 2003).

With the coming into being of the concept “Green Building”, various green building certification systems are gaining popularity worldwide. Contributing to the development of sustainability in a concrete and feasible way, they check the sustainability aspects of the buildings, including the design phase, construction phase, operation phase, and end of life, in order to achieve the harmonization among the triple bottom line: People, Planet, and Profit (Richards, 2012). The rating systems normally consist of several categories, assessing the environmental, economical and social aspects of the building. Related credits are listed under each category. A defined amount of credits have to be accumulated to achieve the targeted certification level.

In most certification schemes, the credits can provide design and operational guidance. The other way around, two ways of utilizing the certification schemes appear feasible: certification oriented design during early stages and building certification at later stages. By aiding the buildings to achieve their green objectives, different systems contribute on various levels to helping the building achieve national and international standards and requirements about design, operation and demolition (Wang et al., 2012).

1.2 Background of BIM

“A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update, or modify information in the BIM to support and reflect the roles of that stakeholder. The BIM is a shared digital representation founded on open standards for interoperability.” (NIBS, 2007)

The National Institute of Building Science (NIBS), an organization pioneering in BIM development in the U.S., defined BIM with the above sentences in the document “National Building Information Modeling Standard”, which covers the scope of core standards, technical specifications and deployment methodologies of BIM.

To organize the definition in a more systematic way, BIM indicates two layers of meanings:

BIM-Building Information Modeling, is a model-based process which integrates the digital building information into one model, like geometrical information (location, size, shape, space, function) and construction material data, etc., and helps to plan, design, construct and manage the buildings and infrastructures (Autodesk, 2015).

BIM-Building Information Model, is a model that provides and displays detailed information of a project, which can be used in later project process to simplify the procedure, reduce the workload, and increase the efficiency.

Early in 2004, Patric MacLeamy sketched a figure consisting of some curves (Figure1) and named the figure after himself. The curves demonstrated the typical situation in construction industry, which indicated that the abortive work at later stage of a project is costly. The shifting of the design effort to early phase is suggested to collectively resolve the problems and reduce the whole life cycle cost, namely BIM/IPD (Integrated Project Delivery) effort. The development and application of the BIM concept is an on-going trend in the whole construction industry. In 2008, McGraw-Hill Construction described the competitive advantages of BIM in their “SmartMarket Report”, and case studies were carried out from multiple perspectives including usage of BIM, value of using BIM, impact of BIM on internal and external processes and BIM infrastructure. 82% of BIM experts believe that BIM is having a very positive impact on their company’s productivity. It helps realize the synchronization among various stakeholders, reduces the communication difficulties among different project teams, avoids redundant project documentation and repeated work (Young et al., 2008).

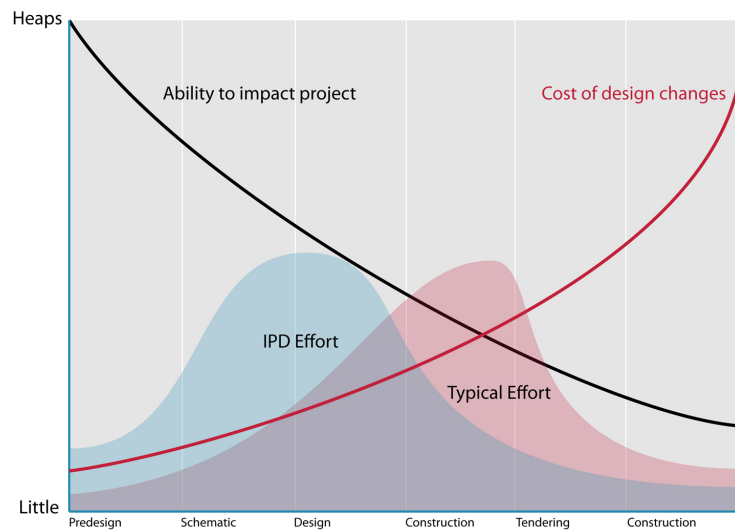


Figure1. MacLeamy Curve. (Davis, 2011)

Despite of the benefits, BIM practitioners are facing various challenges considering BIM implementation:

- Lack of BIM demands (few administrative prescriptions or incentives)

- Impediments from the market (entrenched 2D drafting practices, conventional documentation guidelines and submission procedures)
- Steep learning curve and high knowledge threshold for BIM specialist
- Lack of market demand of skilled BIM manpower (Building and Construction Authority, 2011)

The development of BIM also stimulates the development of relating standards. When different stakeholders and practitioners are brought together in a project, it is essential to consider the issue of how to work efficiently, especially when digital tools are applied. As a leading pioneer in BIM development, buildingSMART developed methodologies relating to three aspects: terminology, process and data storage, which are later accepted as ISO standards (BuildingSMART, 2015). Table1 shows the list of the BIM related international framework developed by buildingSMART with the specific standard name and concise summary of the content.

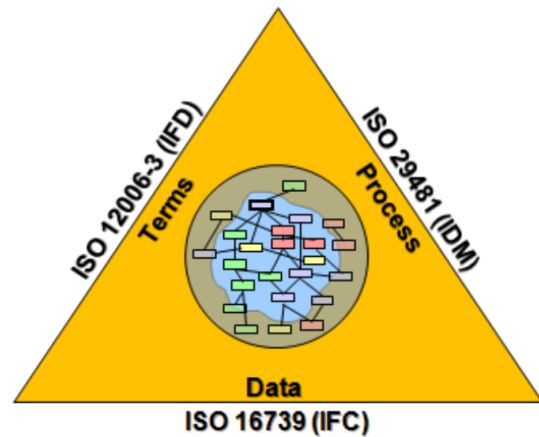


Figure2. buildingSMART Standard Triangle, including three main standards for process, data and terms (BuildingSMART, 2015).

Standard	Name	Content
ISO 12006-3:2007	Building construction -- Organization of information about construction works -- Part 3: Framework for object-oriented information	What information to share
ISO 29481-1:2010	Building information modeling - Information delivery manual (IDM)- Part 1: Methodology and format	When and which information to be communicated
ISO 16739:2013	Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries	How to share data

Table1. BIM related international framework developed by buildingSMART

The Industry Foundation Classes (IFC) standard defines exchange format for building information between different parties. By providing a computer understandable format, the IFC model allows various data to be exchanged. As a supplement to IFC, the International Framework for Dictionaries (IFD) is a terminology standard, which describes construction related concepts and terms, and uses globally unique identifiers (GUID) as information carrier

to replace words. By using GUID, construction materials can be communicated easily between different creators and viewers. Referring to processes, the Information Delivery Manual (IDM) defines when which information and when should be communicated among participants (NIBS, 2012).

1.3 BIM-based green building certification

The market is always demanding better solutions to simplify the process of green building certification, and BIM integration is suggested to be an approach. The match-up of certification requirements and BIM functionalities is theoretically feasible, but when the practical problems are handled at assessment credit-level, various constraints do exist.

The example of energy optimization with BIM is given here to explain the current situation. As described in several documentations, BIM has the capability to provide different scenarios at design stage, to help the designers adjust the design, thus optimizing the energy performance of the building. Meanwhile, potential credits that relate to energy performance in certification schemes may be achieved (Jalaei & Jrade, 2014). However, while considering from a detailed level, a concrete framework that matches up the required documents with generated files from BIM is not yet clear. Can the exported documentation be used directly as the submittals for certification? When not, what extra work needs to be done to fill the gap? Similar questions are rarely discussed, but actually important for the BIM process in green building certification system.

Chapter 2. Methodology

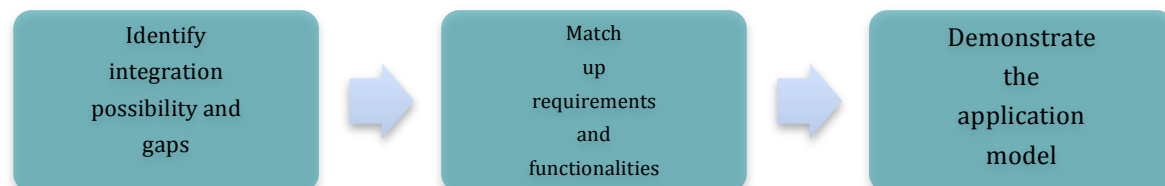
2.1 Scope of research

This research attempts to look at the integration of BIM and potential credits of green building certification system from a systematic perspective and detailed level, using LEED certification and LEED v4 BD+C rating system as a case, and trying to streamline the required documentation with BIM tools. However, credits that can already be supported by traditional design tools are excluded. It is intended to figure out an integration framework of LEED submittals and BIM documentation.

Questions to be discussed:

- Which credits in LEED v4 BD+C certification system can be supported by BIM tools in the documentation process?
- Which BIM tools can be used for integration?
- To which credit can BIM tools contribute the most/least?
- What are the advantages and obstacles of integration?
- How can BIM enhance the certification process?

2.2 Research approach



Chapter 3. Introduction of LEED certification and LEED V4 BD+C rating system

Among all the green building certification systems, LEED, DGNB, BREEAM, Green Star, HQE etc. Leadership in Energy and Environmental Design (LEED) is the most widely recognized and globally applied. By January 2015, there are more than 69,000 LEED building projects located in over 150 countries and territories (USGBC, 2015). As of April 2014, the top ten countries for LEED outside of the U.S. are ranked below based on the amount of the gross square meter.

Rank	Nation	Gross Square Meter (GSM) of LEED-certified space (million)	Total GSM of LEED-certified and registered space (millions)	Total number of LEED-certified and registered projects
1	Canada	17.74	58.66	4,068
2	China	14.30	96.22	1,638
3	India	11.64	66.22	1,657
4	South Korea	3.84	16.61	242
5	Taiwan	2.98	6.97	114
6	Germany	2.90	7.32	365
7	Brazil	2.85	23.24	829
8	Singapore	2.16	3.86	91
9	United Arab Emirates	1.82	47.16	850
10	Finland	1.45	3.56	148

Table2. The ranking of the top 10 countries for LEED outside of the U.S. (USGBC, 2014)

3.1 Assessment categories

LEED provides various rating systems like Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance etc. A proper rating system should be chosen by the project team to be the best adaptation according to the project detailed information before registration. LEED BD+C (Building Design + Construction) is for buildings that are new construction or major renovation, which can be applied to the following building types:

- New Construction and Major Renovation
- Core and Shell Development
- Schools
- Retail
- Data Centers
- Warehouses and Distribution Centers

- Hospitality
- Healthcare
- Homes and Multifamily Lowrise
- Multifamily Midrise (USGBC, 2014)

When an appropriate rating scheme is chosen, a credit scorecard should be used to calculate the total points a project can finally accumulate with project analysis, consulting, documentation and filing etc. in the project team. In LEED BD+C, after meeting the requirements of all the prerequisites, the points are accumulated based on 9 credit categories, covering various environmental and social aspects of the performance of a project.



Figure3. Credit categories in LEED BD+C certification system (USGBC, 2014)

3.2 Scoring system

LEED BD+C has four levels of certification, depending on the achieved point thresholds:

- Certified, 40–49 points
- Silver, 50–59 points
- Gold, 60–79 points
- Platinum, 80 points and above

Chapter 4. Introduction of BIM tools

In order to realize the expected BIM functionalities and applications, BIM tools are the essential part of the whole process. Principally, BIM tools can be classified into two categories:

- modeling tool
- simulation and analysis tools

1) The modeling tools.

These tools are normally utilized at relatively earlier stage. The information detail level of the model always depends on how much data can be acquired from the real building. For instance, Autodesk Revit Architecture tool shows the design concept of the building, and the material used for each building components. And the Revit MEP (Mechanical, Electrical, Plumbing) tool would help the users to create a model that can be used to check the whole building engineering system, to do engineering analysis like plumping clash detection, duct and pipe calculation, etc. Different tools with various functions allow the model to contain details focusing on different perspectives.

2) The simulation and analysis tools.

Traditionally, when the owner would like to do the engineering analysis of a project, the architecture company had to work with engineers who need to redraw the project in the engineer software to do demanded simulation and analysis, which adds to workload, protracts the whole work process, and also financially increases the cost to the owner. This problem also applied to handling sustainability aspects. However, BIM tools reduce replication of work, when software solutions are sufficiently compatible.

These software, plug-ins, or web-based tools can either import BIM models, or be integrated with the modeling tools to run simulation or conduct further analysis. They have basically two functions relating to various sustainability perspectives: water efficiency, energy efficiency, thermal comfort, visual comfort etc.:

- Optimizing the design
- Analyzing the completed construction

By either communicating with IFC file, or directly analyzing on the model software without leaving the design environment, further evaluation can be completed after inserting necessary parameters into the model. Temporarily, there are the following types of simulation tools:

- Energy simulation: To run an energy simulation, the HVAC information, technical settings of the building should be predefined in the tool. Normally a baseline energy model should be created as well, referring to certain standard. A comparison between the baseline

model and the proposed design model is necessary in order to show the improved performance.

- **LCA tool:** Compared with traditional excel-based LCA tool, the LCA software is theoretically more efficient. First of all, the software extracts necessary information from the model and form a list structuring construction component categories. Under each category, each material in the model can be found. The software will link each material to the data in its material database, and calculate the total environmental effect of different indicators. It is necessary to manually define the material when the material from the model is new to the LCA tool, but the tool will automatically memorize it for future use. In the end, the LCA tool can also communicate the newly defined materials back into the model.

For LCA tools in different regions, the applied LCA databases normally differ as well. It is essential to choose the LCA tool with appropriate database and assessment scope.

- **Lighting simulation:** including simple daylight simulation and combination simulation. The daylight simulation shows the sun path around the building at different time of a specific day in a year based on the location and climate zone of the project. The climate database imbedded in the software utilizes the data from the climate observation station which locates the nearest from the project. It is also possible to get a distribution map for different daylight factors or illuminance values at different points inside of the building with different colors.

However, the combination simulation will include the effects of the artificial lighting that should be previously set up in the model. The illuminance level of the chosen area will be calculated. It is possible to run the simulation for the whole building, or only on certain chosen area when necessary, which will avoid long calculation periods and large amounts of data.

- **Water consumption analysis:** Adding plumbing fixtures and defining the flush/flow rate in the model is the first but not last step. As more fixtures in the building do not equal to more consumption, so the consumption amount should not be calculated based on the number of fixtures, but the information of building occupancy and usage frequency, which the calculation tool can obtain from the model directly.

- **Computational Fluid Dynamics (CFD) simulation:** CFD simulation contributes to wide range of industries. For instance, it can be done for a product to improve the aerodynamic characteristics, or for a building, to help the architects to improve the thermal comfort level of the occupants by providing a qualitative or quantitative prediction of fluid flows (Kuzmin, 2009).

The improvement of BIM does not only affect the working process of the industry, but also the development of the software. At the beginning of BIM boom, the trend went towards the compositing of the architectural files with those engineering analysis, and allows BIM models to be exported and imported for the communication on different platforms. It is possible to

export the model as several different formats (including DWG, DWF, XML etc.) for various purposes. For instance, in many cases, a gbXML file is required in order to realize the successful import into engineering analysis tools like Green Building Studio, Ecotect etc. The energy model of gbXML is created based on spaces, surfaces and zones.

- Spaces: Heat loss or gain due to internal activities including occupancy, lighting, equipment, HVAC and heat exchange with exterior;
- Surface: Heat transfer through building exterior envelope, interior walls and floors;
- Zones: Several spaces sharing the same orientation, function, HVAC system etc (Autodesk, 2014).

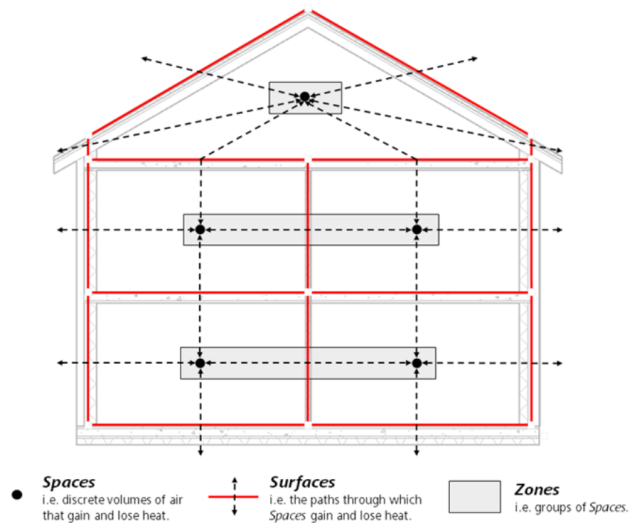


Figure4. An Energy Analytical Model consisting of spaces, surfaces and zones (Autodesk, 2014)

In other words, a gbXML file will include walls, roofs, floors, openings, room function, occupancy, and HVAC system information.

However, technical problems come out very often while importing the BIM models because of different compatibility levels or format issues. For instance, the gbXML file (UTF-16 format) from Revit is not encoded in the UTF-8 format that Ecotect can accept, so the warning (Figure5) would pop out when the format conversion was not conducted.

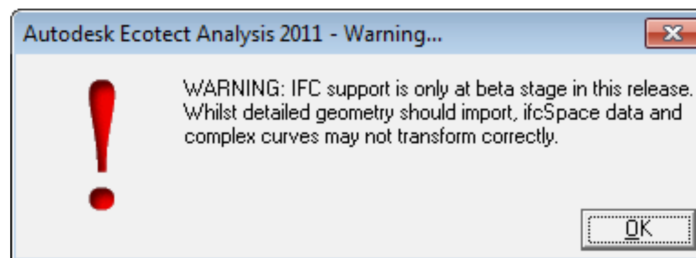


Figure5. Appeared warning when importing the BIM model from Revit to Ecotect without converting the codes

However, with the development of BIM, many software companies attempt to run the simulations directly on the modeling software, in order to avoid disorder and realize seamless communication between base model and the simulation tool by one click on the modeling software. An example can be given here. Instead of developing the analysis software Ecotect further, Autodesk discontinues the Ecotect analysis from March 20th, 2015, and is trying to integrate similar functionalities into the Revit product family, shifting the development efforts to BIM solution (Autodesk, 2015). Besides Autodesk, many other engineering software companies (Design Builder, IES Virtual Environment etc.) developed various plug-ins that can be integrated with BIM modeling tools like Revit, Sketchup, which indicates the development of the BIM concept from another perspective (Autodesk, 2015).

Chapter 5. Integration framework

The application of the BIM concept covers various fields according to stakeholders' needs and business focus. From the introduction of different BIM tools, it can be indicated that building analysis and simulation is an essential aspect that can be integrated with BIM, including lighting, energy consumption, thermal analysis, life cycle assessment etc., most of which share the same topics with certain credits in LEED v4 certification scheme. Therefore it leads to some interesting questions and also the topic of this report:

- Is it possible to integrate BIM into LEED certification process?
- If possible, what are the essential points to connect them?
- With which method?
- What are the benefits and obstacles?

Now that there are already connections and overlapping areas of these two topics BIM and LEED, then there should be a way to integrate them. First of all, a draft integration framework is created by highlighting the credits that have the potential to be integrated with BIM in LEED certification system, with bars indicating the weight of these credits in the whole rating system. These credits are listed below:

- Indoor Water Use Reduction (Prerequisite and Credit)
- Minimum Energy Performance (Prerequisite) – Whole Building Simulation
- Optimize Energy Performance (Credit) – Whole Building Simulation
- Building Life-Cycle Impact Reduction – Whole building life-cycle assessment
- Building Product Disclosure and Optimization – Environmental Product Declarations
- Thermal Comfort
- Daylight

Nr.	Credit Name	Possible Points:	Weight	Nr.	Credit Name	Possible Points:	Weight
Minimum Program Requirements				Energy and Atmosphere			
Prereq 1	Permanent Location in existing Land			Credit 3	Advanced Energy Metering	1	0,91%
Prereq 2	Use of reasonable LEED Boundaries			Credit 4	Demand Response	2	1,82%
Prereq 3	Comply with Project Size Requirements (min. 93m2)			Credit 5	Renewable Energy Production	3	2,73%
Credit 1	Integrative Process	1	0,91%	Credit 6	Enhanced Refrigerant Management	1	0,91%
Location and Transportation				Green Power and Carbon Offsets			
Credit 1	LEED for Neighborhood Development Location	16	14,55%	Credit 7	Green Power and Carbon Offsets	2	1,82%
Credit 2	Sensitive Land Protection	1	0,91%	Materials and Resources			
Credit 3	High Priority Site	2	1,82%	Prereq 1	Storage and Collection of Recyclables		
Credit 4	Surrounding Density and Diverse Uses	5	4,55%	Prereq 2	Construction and Demolition Waste Management Planning		
Credit 5	Access to Quality Transit	5	4,55%	Credit 1	Building Life-Cycle Impact Reduction	5	4,55%
Credit 6	Bicycle Facilities	1	0,91%	Option 1	Historic Building reuse	5	4,55%
Credit 7	Reduced Parking Footprint	1	0,91%	Option 2	Renovation of abandoned or blighted Building	5	4,55%
Credit 8	Green Vehicles	1	0,91%	Option 3	Building and material reuse	2	1,82%
Sustainable Sites				Option 4	Whole-Building Life-Cycle Assessment	3	2,73%
Prereq 1	Construction Activity Pollution Prevention			Credit 2	Building Product Disclosure and Optimization - Environmental Product Declarations	2	1,82%
Credit 1	Site Assessment	1	0,91%	Option1.	Environmental Product Declaration (EPD)	1	0,91%
Credit 2	Site Development--Protect or Restore Habitat	2	1,82%	Option2.	Multi-Attribute Optimization	1	0,91%
Credit 3	Open Space	1	0,91%	Credit 3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	1,82%
Credit 4	Rainwater Management	3	2,73%	Credit 4	Building Product Disclosure and Optimization - Material Ingredients	2	1,82%
Credit 5	Heat Island Reduction	2	1,82%	Credit 5	Construction and Demolition Waste Management	2	1,82%
Credit 6	Light Pollution Reduction	1	0,91%	Indoor Environmental Quality			
Water Efficiency				Prereq 1	Minimum Indoor Air Quality Performance		
Prereq 1	Outdoor Water Use Reduction			Prereq 2	Environmental Tobacco Smoke Control		
Prereq 2	Indoor Water Use Reduction			Credit 1	Enhanced Indoor Air Quality Strategies	2	1,82%
Prereq 3	Building-Level Water Metering			Credit 2	Low-Emitting Materials	3	2,73%
Credit 1	Outdoor Water Use Reduction	2	1,82%	Credit 3	Construction Indoor Air Quality Management Plan	1	0,91%
Credit 2	Indoor Water Use Reduction	6	5,45%	Credit 4	Indoor Air Quality Assessment	2	1,82%
Credit 3	Cooling Tower Water Use	2	1,82%	Credit 5	Thermal Comfort	1	0,91%
Credit 4	Water Metering	1	0,91%	Credit 6	Interior Lighting	2	1,82%
Energy and Atmosphere				Credit 7	Daylight	3	2,73%
Prereq 1	Fundamental Commissioning and Verification			Option 1.	Simulation: Spatial Daylight autonomy and annual sunlight exposure		
Prereq 2	Minimum Energy Performance			Option2.	Simulation: Illuminance calculations		
Option1.	Whole Building Simulation			Option3.	Measurement		
Option2.	Prescriptive compliance: ASHRAE 50% Advanced Energy Design Guide			Credit 8	Quality Views	1	0,91%
Option3.	Prescriptive compliance: Advanced Buildings Core Performance Guide			Credit 9	Acoustic Performance	2	1,82%
Prereq 3	Building-Level Energy Metering			Innovation			
Prereq 4	Fundamental Refrigerant Management			Credit 1	Innovation	5	4,55%
Credit 1	Enhanced Commissioning	6	5,45%	Credit 2	LEED Accredited Professional	1	0,91%
Credit 2	Optimize Energy Performance	18	16,36%	Regional Priority			
Option 1	Whole-Building Energy Simulation	18	16,36%	Regional Priority		4	3,64%
Option 2	Prescriptive Compliance: ASHRAE advance Energy Design Guide / ASHRAE 50% Small to Medium Office Buildings	5	4,55%	Total			
						110	

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Table3. LEED v4 BD+C checklist with highlighted (blue) credits indicating possibilities to be integrated with BIM (adapted from the LEED v4 BD+C checklist)

At first sight, there also seems to be high possibilities to integrate the credits “Low-Emitting Materials” and “Interior Lighting” with BIM easily by generating the list of materials and lighting fixtures with BIM tool. However, when LEED required documentation for these two credits are checked thoroughly, it can be found that “Low-Emitting Materials” requires complicated calculation and manual work has to be done for “Interior Lighting” to list the lighting control devices, which cannot be simply realized by BIM. So these two credits are not discussed here.

Basically, the integration of the highlighted credits and BIM process can be classified into the following three topics, and the matchup of each topic and related credits is shown in the table below:

- Resource efficiency and BIM
- Environmental impacts reduction and BIM
- Occupant comfort improvement and BIM

Integration topic	Related LEED Credits
Resource efficiency and BIM	<ul style="list-style-type: none"> • Indoor Water Use Reduction (Prerequisite and Credit) • Minimum Energy Performance (Prerequisite) • Optimize Energy Performance (Credit) • Daylight
Environmental impacts reduction and BIM	<ul style="list-style-type: none"> • Building Life-Cycle Impact Reduction-Whole building life-cycle assessment • Building Product Disclosure and Optimization - Environmental Product Declarations
Occupant comfort improvement and BIM	<ul style="list-style-type: none"> • Thermal Comfort • Daylight

Table4. Integration topics of BIM and LEED credits

Some LEED credits require the documentation like particular drawings of the project, which can be provided already by conventional CAD tools. However, with software like Revit, it would be more efficient during the documentation process, and also avoid chaos by automated synchronization and update of all changes of files. In this report, this advantage of BIM will not be discussed due to the overlapping function between conventional tools and BIM tools. Only the credits that can be achieved by submitting the documents, which cannot be provided by conventional CAD software but BIM tools, will be analyzed here.

5.1 Resource efficiency and BIM

Resource efficiency of a project covers water, energy and material use reduction in a project’s construction and operation stages. In construction stages, it is targeted to minimize the water and energy use to deliver the project. In operation stages, it is necessary to utilize the facilities and assets that are efficient in using water and energy. And action plans or programs that contribute to efficiency are encouraged as well (Mactavish et al., 2013).

BIM brings not only efficiency in project delivery, but also in the project's resources use. Using BIM process to achieve resource efficiency by building performance estimation and optimization, it makes BIM implementation into certification process possible. In order to have a resource efficient building eventually, it is necessary to carry out a series of estimation and adjustment on the designed model (Figure 6). In this case, BIM tools and process can help to ease the workload and speed up the process, by gathering project information directly, running the estimation by demand, seeking the optimizing potentials and providing the appropriate resource efficiency actions.

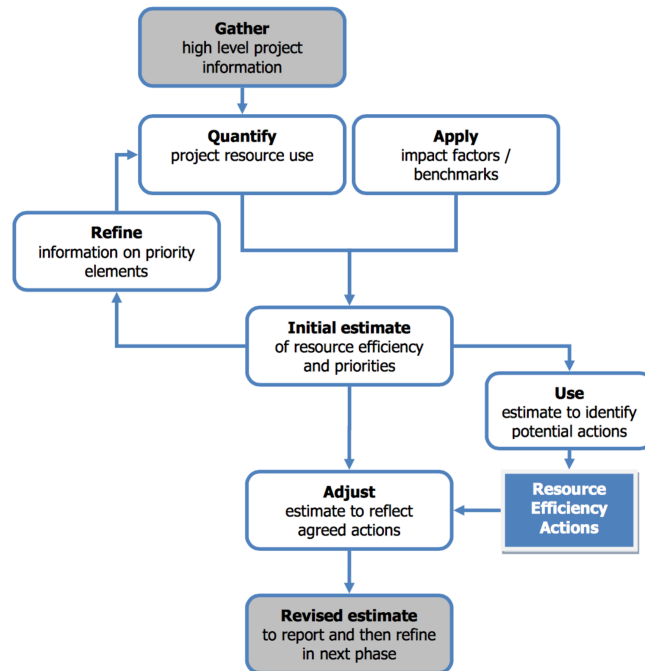


Figure6. BIM workflow for resource efficiency (Mactavish et al., 2013)

At the same time, the accuracy of the estimation will rely on the BIM tools and the manual input, which is the main concern of integration on this topic. Which building information is extracted from the BIM tool, what are the default values while running the simulations, what standards are referred to... Only when all these questions are figured out and properly handled, a reliable and plausible integration with the BIM workflow can be established.

5.1.1 Water Efficiency

WE Prerequisite Indoor Water Use Reduction

WE Credit Indoor Water Use Reduction

This prerequisite and credit encourage reducing indoor water consumption by selecting water-efficiency appliances and fixtures including toilets, urinals, private lavatory faucets, and showerheads for the building. It is compulsory to reduce aggregated water consumption by 20% from the baseline (refer to Table31 in Appendix) to achieve the prerequisite. However, better performance (Table 5) is required to get points of the credit. In order to achieve the credit, it is encouraged to use alternative water sources and minimize potable water demand. Besides, water can be reused for outside irrigation and inside toilet flushing, which requires least treatment.

Requirements	Achieved Credits
25% water use reduction	1
30% water use reduction	2
35% water use reduction	3
40% water use reduction	4
45% water use reduction	5
50% water use reduction	6

Table5. Points for reducing indoor water use

LEED required documentation	Predicted BIM Integration
Alternative water narrative	None
Product cut sheets, manufacturers' information	By adding the water fixtures and detailed product information into the model, it is possible to create a schedule of installed appliance in the BIM model
Indoor water use calculator	Possibility of integrating the calculator into BIM tool. Information of occupancy and flush rate of appliance will be extracted directly from BIM model to complete the calculator.

Table6. Integration framework of BIM and LEED WE credit Indoor Water Use Reduction

5.1.2 Energy and Atmosphere

In LEED BD+C certification system, there are two credits related to energy performance, one being Prerequisite Minimum Energy Performance, the other being Credit Optimize Energy Performance. The requirements and fulfill options are listed below:

EA Prerequisite Minimum Energy Performance

Option 1: Whole-building energy simulation

For different building types, minimum percentage of improvement need to be achieved (5% for new construction, 3% for major renovations, or 2% for core and shell projects). The comparison carries out between the proposed building performance and the baseline building performance. It should be noticed that the projects must meet the minimum percentage savings before achieving credit for renewable energy systems.

Option 2: Prescriptive compliance.

ASHRAE 50% Advanced Energy Design Guide should be followed.

Option 3: Prescriptive compliance.

Advanced Buildings Core Performance Guide should be followed. However, the project must be less than 9290m² (USGBC, 2014).

EA Credit Optimize Energy Performance

Option 1 Whole Building Energy Simulation.

The achieving path of this option is the same as that in prerequisite, but the achieved credit points are awarded based on the performance of proposed building compared with the baseline.

Option 2 Prescriptive Compliance.

ASHRAE 50% advance Energy Design Guide should be followed. If option2 is chosen, then the project has to use Option 2 in EA Prerequisite as well (USGBC, 2014).

It is easily seen that the requirements for prerequisite and credit are closely linked to each other. When EA credit is achieved, the prerequisite is automatically reached as well. Basically, the options for achieving EA prerequisite and EA credit consist of two types of options: prescriptive compliance and performance compliance (USGBC, 2010).

Building Type	Prescriptive compliance	Performance compliance
New Construction, Core and Shell, Retail, Distribution Centers, Hospitality	Option 2: Prescriptive compliance: ASHRAE 50% Advanced Energy Design Guide Option 3: Prescriptive compliance: Advanced Buildings Core Performance Guide (the project must be less than 9 290m ²)	Option 1: Whole-building energy simulation
Healthcare, schools	Option 2: Prescriptive compliance: ASHRAE 50% Advanced Energy Design Guide	Option 1: Whole-building energy simulation
Data Center, Warehouse or Laboratory		Option 1: Whole-building energy simulation

Table7. Different compliance categories for EA Prerequisite Minimum Energy Performance

Among all the above compliance paths, Option1 whole-building energy simulation is possible to be incorporated with the BIM workflow.

In order to accomplish the energy simulation, the following steps are to be followed:

1. Developing a preliminary energy model (preliminary design phase)
2. Modeling HVAC Systems (preliminary design phase)
3. Building the proposed energy model
4. Create baseline energy model
5. Calculating energy cost savings (on an energy cost basis using actual utility rates or the state’s average energy prices) (USGBC, 2014)

The first two steps are only necessary at preliminary design phase to help the design team to optimize the energy system, and reduce the energy consumption. When the project is already finished, Step 3 should be considered as the first move. With BIM tools, the following three steps can be completed relatively efficiently.

Step3. Building the proposed energy model

Based on the basic information like building massing, envelope, and geometry information (location, orientation, etc.), BIM tools can run an energy simulation by setting the designed energy system that includes information about building operating schedule, HVAC system, space function etc.

Step4: Create baseline energy model

In order to conform to the LEED requirements, the baseline energy model should be set up according to ASHRAE 90.1-2010 Appendix G. A few points need to be altered with the BIM tool in the proposed model in order to create the baseline building. After that, an alternative energy simulation can be carried out on this baseline model.

Aspects	Proposed Building Performance	Baseline Building Performance
Design Model	Consistent with the design document, including information about fenestration and opaque envelope types and areas; interior lighting power and controls; HVAC system types, sizes and controls; service water heating systems and controls etc.	The baseline building design shall be modeled with the same number of floors and identical conditioned floor area as the proposed design.
Space Use Classification	Building type or space type	Same

Schedules	Schedules capable of modeling hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation	Same (It can be different only when the nonstandard efficiency measures exist, like automatic lighting controls, automatic natural ventilation controls etc. In no case shall schedules differ where the controls are manual e.g., manual operation of light switches or manual operation of windows)
Building Envelopes	All components of the building envelope in the proposed design shall be modeled as drawn in the architecture design	Different Equivalent dimensions shall be assumed for each exterior envelope component, as to the alteration in the baseline model, following aspects shall be applied: <ul style="list-style-type: none"> 1. Orientation (rotate the building 90, 180, and 270 degree, and averaging the result) 2. Opaque Assemblies 3. Vertical Fenestrations 4. Skylights 5. Roof solar reflectance and thermal emittance 6. Existing buildings
Lighting	When complete lighting system exists, then model the actual situation, when no lighting system is specified, then model it in accordance with the Building Area Method for the appropriate building type.	Different Set equal to the maximum allowed for the corresponding method and category of building area and space
Thermal Blocks-HVAC zone designed	Model according to real situation	Same
Thermal Blocks-HVAC zone not designed	Model based on similar internal load densities, occupancy, lighting, thermal and <i>space</i> temperature schedules, and in combination with certain guidelines	Same
HVAC System	When complete HVAC system exists, the model should reflect the actual system type. When no heating system is specified, the heating classification shall be assumed to be	Different Based on Baseline HVAC system type (refer to basic HVAC system

	electric, and characteristics should be same with baseline building design.	in Appendix Table32 and Table33)
	When no cooling system exists, it should be the same with baseline building design.	
Service Hotwater system	<p>When complete hotwater system exists, the model should reflect the actual system type, capacities and efficiency.</p> <p>When hotwater system will be installed, but no one is specified yet, then model it the same with the baseline design.</p> <p>When no hotwater system is planned, then no system should be modeled.</p>	<p>Different</p> <p>When complete hotwater system exists, the model should reflect the actual system type, capacities and efficiency.</p> <p>When no system is specified, then the equipment should match the minimum efficiency requirements, Where the energy source is electricity, the heating method shall be electrical resistance.</p> <p>When no hotwater system is planned, then no system should be modeled.</p>
Exterior Conditions	<p>a. Shading by adjacent structures and terrain</p> <p>b. Ground temperatures for below-grade wall and basement floor heat loss calculations</p> <p>c. Water main temperatures for service water heating calculations</p>	Same

Table8. Modeling requirements of the energy model for proposed design building and the baseline building (Adapted from ASHRAE 90.1-2010 Appendix G) (ASHRAE Standards Committee, 2010)

Step5: Calculating energy cost savings

When the comparison between the baseline model and proposed design model is completed, the potential cost saving from energy improvement can be calculated based on the local energy price.

LEED required documentation	Predicted BIM Integration
ASHRAE 90.1-2010 Appendix G energy modeling inputs (Baseline model)	Based on the designed BIM model, energy simulation can apply the ASHRAE 90.1 defaults to the project directly
Input and output reports from modeling software	Energy analysis report
Target Finder results and summary	The information from energy analysis report can be used
Energy consumption and demand for each building end use and fuel type	Energy analysis report
Fuels rates	Calculation based on the energy analysis report

Table9. Integration framework of BIM and LEED energy performance credit

5.1.3 Indoor Environmental Quality

IEQ Credit: Daylight

The improvement of daylight use reduces the use of artificial light, therefore contributing to energy efficiency. This credit will be discussed in detail under the third topic: Occupant comfort improvement and BIM.

5.2 Environmental impacts reduction and BIM

Buildings consume large amounts of materials and energy. Decisions at early stage of a project have great influence on the environmental impacts, which makes life cycle assessment critically important. In order to incorporate BIM software into LCA, a BIM model should be first created. Once BIM tools are used to assess the environmental impacts of a project, the design-feedback process will be quite efficient. When material quantities are inserted into the BIM model, the BIM software can calculate the environmental impacts like embodied carbon footprint. Sensitivity analysis can be conducted by altering materials, replacement cycle, and quantitative values etc. to analyze the result and optimize the design (Basbagill et al., 2013).

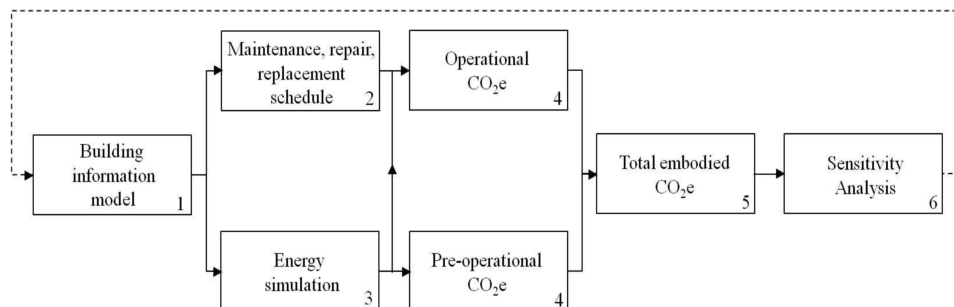


Figure7. BIM and LCA implementation method for carbon footprint (Basbagill et al., 2013)

BIM tools are widely used by designers, but the integration with LCA is still at the early stage. Therefore, there are various constraints of the software. It is difficult for some BIM tools to extract exact building information from the complicated architectural design, which makes it necessary to manually define the materials later. Besides, each LCA tool has its own predefined regional LCA database, which limits the application of the tool on projects in other regions. And the development of the new database is relatively time-consuming. The integration of BIM tools and LEED credits on environmental impacts reduction is discussed below.

5.2.1 Material and Resources

MR Credit Building Life-Cycle Impact Reduction

In order to encourage reducing the environmental impacts of the buildings, 4 options are provided to achieve this credit.

Option 1. Historic building reuse

Option 2. Renovation of abandoned or blighted building

Option 3. Building and material reuse

Option 4. Whole-building life-cycle assessment (USGBC, 2014).

The first three alternatives are suitable for existing buildings, and have special requirements for the project, while option 4 can be applied to all new constructions, and integrated with BIM. A life cycle assessment of the whole building, including structure and enclosure, should be conducted, to demonstrate a minimum of 10% reduction, compared with a baseline building, in at least three of the following six impact categories, one of which must be global warming potential.

- global warming potential (greenhouse gases), in CO₂e (GWP);
- depletion of the stratospheric ozone layer, in kg CFC-11 (ODP, POCP);
- acidification of land and water sources, in moles H⁺ or kg SO₂ (AP);
- eutrophication, in kg nitrogen or kg phosphate (EP);
- formation of tropospheric ozone, in kg NO_x or kg ethene (POE);
- depletion of nonrenewable energy resources, in MJ (USGBC, 2014).

The following parameters should be kept the same to make the comparison accurate and plausible.

1. LCA scope requirements (data sets, indicators, 60-year building service life)
2. Location (same climate zone and project site)

3. Building function
4. Gross floor area
5. Orientation
6. Operating energy performance (USGBC, 2014).

Among the above six points, operating energy performance is relatively important. It reminds designers to not sacrifice too much energy performance of the building, to achieve a better LCA result. A balance between the two aspects should be always considered.

The LCA tools can normally import a set of materials into the BIM model, but not establish a baseline building. However, for the whole building LCA credit in LEED, it is typically done via one of the following two methodologies to establish the baseline model:

- Taking the finished model and modifying certain materials to achieve the credit, for example insulation and concrete type.
- Tracking the various decisions that have been chosen via the LCA exercise at every stage of model development. And using one of the earlier designs as the baseline.

LEED required documentation for Option4	Predicted BIM Integration
Description of LCA assumptions, scope, and analysis process for baseline building and proposed building	Report from LCA tool, which can extract the material information from the BIM model
Life-cycle impact assessment summary showing outputs of proposed building with percentage change from baseline building for all impact indicators	Report from LCA tool, which can extract the material information from the BIM model

Table10. Integration framework of BIM and LEED MR Credit Building Life-Cycle Impact Reduction Option4

MR Credit Building Product Disclosure and Optimization - Environmental Product Declarations

This credit encourages using environmentally preferable products in the building, and select manufacturers who can provide products with self-declaration or third-party declaration, which conforms to international standards. Two options are available here to achieve this credit.

Option 1. Environmental product declaration (EPD) (1 point)

Use at least 20 different permanently installed products sourced from at least five different manufacturers that meet one of the disclosure criteria below.

- Product-specific declaration (valued as one quarter of a product)
- Environmental Product Declarations which conform to ISO 14025, 14040, 14044, and EN 15804 or ISO 21930 and have at least a cradle to gate scope.
 - A. Industry-wide (generic) EPD (valued as one half of a product)
 - B. Product-specific Type III EPD (valued as one product)
- USGBC approved program (USGBC, 2014).

Option 2. Multi-attribute optimization (1 point)

Use products that comply with one of the criteria below for 50%, by cost, of the total value of permanently installed products in the project. Products will be valued as below.

- Third party verified products that demonstrate impact reduction below industry average in at least three of the following categories are valued at 100% of their cost for credit achievement calculations.
 - A. global warming potential (greenhouse gases), in CO₂e;
 - B. depletion of the stratospheric ozone layer, in kg CFC-11;
 - C. acidification of land and water sources, in moles H⁺ or kg SO₂;
 - D. eutrophication, in kg nitrogen or kg phosphate;
 - E. formation of tropospheric ozone, in kg NO_x or kg ethene;
 - F. depletion of nonrenewable energy resources, in MJ.
- USGBC approved program (USGBC, 2014).

Option 2 requires specific information from the product declaration, and it is necessary to compare associated values with industrial average standard. However, Option1 offers more feasibility to integrate with BIM functionality of creating whole building material list and documentation of life cycle assessment. Environmental product declaration (EPD) provides information linked to the product or the production industry, including raw material extraction, manufacturing, and end of life. The program operator of the EPD affects the approach and scope of the declaration. Considering this aspect, the information (e.g. the name of the organization) of the EPD program operator should also be provided in LEED certification. The required documentation of Option1 and possibility of acquiring support from BIM in generating associated files are listed below.

LEED required documentation for Option1	Predicted BIM Integration
MR building product disclosure and optimization calculator (see Table12) or equivalent tracking tool	Possibility of finishing the spreadsheet calculator by referring to the LCA report generated from BIM tool
EPD and LCA reports or compliant summary documents for 100% of products contributing toward credit	Possibility of including the EPD document into the BIM model, and generating with material list when necessary

Table11. Integration framework of BIM and LEED MR credit Building Product Disclosure and Optimization – EPDs

Environmental Product Declarations

Complete all columns with applicable material data for the attempted options. If the option is not attempted, leave the column blank.

General Information (from Materials tab)			Option 1 Environmental Product Declaration			Option 2 Multi-Attribute Optimization		
Material Description	Is the material structure or enclosure?	Material Cost	EPD Program Operator	EPD Type	Weighted EPD Value (#)	Third Party Certification Program	Does the entire product meet local criteria?	Total Sustainable Criteria Value with Location Valuation Factor (\$)
								\$ -
								\$ -
								\$ -
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								\$ -
								\$ -
			Weighted number of products with EPD			Total sustainable criteria value with location valuation factor		
			0			\$ -		

Table12. Building Product Disclosure and Optimization Calculator to track and document product purchases

5.3 Occupant comfort improvement and BIM

The convergence of BIM and facility management is an inevitable trend. Besides making the building more efficient, the other goal of facility management is to improve the comfort level of the occupants (Dibble, 2014). Based on the BIM model, and integrating the results of surveys & interviews of the occupants from other projects, the BIM simulation tool can estimate a general comfort level of the occupants, which may includes lighting, thermal and acoustic aspects. The feeling about comfort of human beings is a rather complicated subject, which leads to one of the problems of some BIM simulation tools: ignoring the varieties of individual demands and comfort level preference (Andrews et al., 2012). Thus, the evaluation system here is quite important to minimize the effect of varieties of preferences.

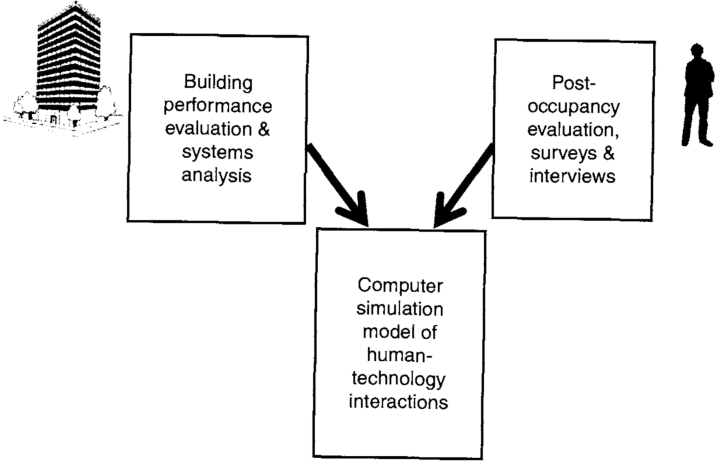


Figure8. BIM comfort level simulation tool workflow (Andrews et al., 2012)

5.3.1 Indoor Environmental Quality

IEQ Credit Thermal Comfort

There are six basic factors affecting the thermal comfort, which are independent from each other, but work together to decide the comfort level.

Environmental factors:

- Air temperature
- Radiant temperature
- Air velocity
- Humidity

Personal factors:

- Clothing Insulation
- Metabolic rate (HSE, 2015)

Two indices are normally referred to indicate the comfort level: Predicted mean vote (PMV) and Predicted percentage of dissatisfied (PPD), which are connected to each other. (See Table 13) PMV ranges from -3(too cold) to +3(too hot), and PPD is then determined based on PMV and indicates the percentage of people who are dissatisfied with the condition (USGBC, 2014).

Category		Description	Allowable predicted mean vote	Allowable predicted percentage dissatisfied
ISO 7730- 2005	EN 15251- 2007			
A	I	Recommended for spaces occupied by very sensitive and fragile persons with special requirements (very young children, elderly, ill)	$-0.2 < PMV < 0.2$	<6%
B	II	Suitable for most new buildings and renovations	$-0.5 < PMV < 0.5$	<10%
C	III	Suitable for existing buildings	$-0.7 < PMV < 0.7$	<15%
	IV	Values other than above; acceptable for only part of year	$PMV < -0.7$ or $PMV > 0.7$	>15%

Table13. Comparison of comfort acceptability ranges, ISO 7730-2005 and EN 15251-2007 (USGBC, 2014)

This credit in LEED requires the achievement of thermal comfort through two aspects: design and control. “Thermal comfort control” asks the project to provide individual thermal comfort controls for at least 50% of individual occupant spaces, to adjust at least one of the environmental factors. However, the requirements of the “thermal comfort design” provide prescriptive compliance methods to help the designers optimize the comfort level of occupants.

Thermal Comfort Design

Option 1. ASHRAE Standard 55-2010 (US)

OR

Option 2. ISO and CEN Standard (International) (USGBC, 2014)

To achieve the “thermal comfort control” requirements, LEED demands the list of spaces by type, quantity, and controls, which can be simply created manually. However, in order to generate the required documentation for “thermal comfort design”, thermal simulation and calculation need to be carried out, which provides large potential of BIM integration. Therefore, only BIM integration possibility with “thermal comfort design” is discussed here.

LEED Required Documentation	Predicted BIM Integration
Option1	
<p>Description of weather data used to determine operative temperatures, relative humidity, outdoor temperatures</p> <p>Plots or calculation results verifying that design parameters meet ASHRAE Standard 55–2010 for 80% acceptability (e.g., psychometric chart; PMV or PPD calculations; ASHRAE Thermal Comfort Tool results; or predicted worst-case indoor conditions for each month)</p>	<p>When the location of the project is defined in the BIM model, corresponding weather data will be extracted from the database, and be displayed within in the output report</p> <p>Based on the basic information (geometric and material and HVAC etc.) of the BIM model, air temperature, radiant temperature and humidity can be calculated by the BIM simulation software. Afterwards, by manually inputting the air velocity, dressing code and metabolic rate of occupants, the comfort level can be calculated with the demanded calculation methods.</p>
Option2	
<p>Documentation to verify thermally conditioned spaces meet ISO 7730 or EN 15251, as applicable</p>	<p>Based on the basic information (geometric and material and HVAC etc.) of the BIM model, air temperature, radiant temperature and humidity can be calculated by the BIM simulation software. Afterwards, by manually inputting the air velocity, dressing code and metabolic rate of occupants, the comfort level can be calculated with the demanded calculation methods.</p>

Table14. Integration framework of BIM and LEED IEQ credit Thermal Comfort

IEQ Credit: Daylight

In order to acquire LEED daylight credit, three options are possible to follow. They are described in LEED Reference Guide for BD+C:

“Option 1 **Simulation:** Spatial Daylight autonomy and annual Sunlight Exposure

Demonstrate through annual computer simulations that spatial daylight autonomy_{300/50%} (sDA_{300/50%}) of at least 55%, 75%, or 90% is achieved. Use regularly occupied floor area.

And demonstrate through annual computer simulations that annual sunlight exposure 1000,250 (ASE_{1000,250}) of no more than 10% is achieved. Use the regularly occupied floor area that is daylit per the sDA_{300/50%} simulations.

Option 2 **Simulation**: Illuminance calculations

Demonstrate through annual computer simulations that Illuminance levels are between 300 lux and 3,000 lux for 9 a.m. and 3 p.m., both on a clear-sky day at the equinox, for the floor indicated in Table15.”

Option 3 **Measurement**

Demonstrate through measurement that Illuminance levels are between 300 lux and 3,000 lux for 9 a.m. and 3 p.m., both on a clear-sky day at the equinox, for at least **75% of regularly occupied floor area** (USGBC, 2014).

New Construction, core and shell, schools, retail, data centers, warehouses and distribution centers, hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of perimeter floor area	Points
75%	1	75%	1
90%	2	90%	2

Table15. LEED Points for the daylit floor area (USGBC, 2014)

For option 1 and option 2, the simulation tool can extract the following information directly from BIM model:

- Building floor plan
- Sun path on site
- Openings
- Material reflectance value: Some lighting simulation tools do not consider the effect of the reflectance of lights from the surface materials, which will lead to inaccuracy of the simulation result.

One crucial point when running the simulation is that not all the spaces should be included in analysis, but only "regularly occupied spaces". The wrong “regularly occupied area” plan will lead to worse simulation result, or even failure to achieve the LEED requirements. According to the definition from USGBC, regularly occupied space is "an area where one or more individuals normally spend time (more than one hour per person per day on average) seated or standing as they work, study, or perform other focused activities inside a building. The one-hour timeframe is continuous and should be based on the time a typical occupant uses the space. For spaces that are not used daily, the one-hour timeframe should be based on the time a typical occupant spends in the space when it is in use. (USGBC, 2015)" Followings are examples of regularly occupied spaces:

- Bank teller station
- Conference room
- Exhibition room
- Hospital patient room
- Hotel front desk
- Hotel lobby
- Information desk
- Private office (USGBC, 2015)

The integration of BIM with this credit will contribute more significantly in the early design phase to assist LEED-oriented design, comparing to the stage after the completion of the project. Proper and necessary modification of the design can be carried out to achieve the demanded daylight level. In compliance with LEED, the simulation should be accurate enough to get the “time-to-spot” value, which is to say, the daylight level of each spot of the simulated space at specific time in a day of the year. A detailed demonstration of how this process can contribute to achieving LEED credit in design phase will be shown in case study part.

LEED required documentation for Option1 and Option 2 simulation	Predicted BIM Integration
Geometric plots from simulations	By extracting building information (location, orientation, openings) from BIM model, lighting report can be generated after the analysis is completed
Narrative or output file describing daylight simulation program, simulation inputs, and weather file	Daylight simulation tool
List of compliant spaces with their annual summary values for sDA and ASE (Option1)	Lighting analysis report
List of compliant spaces with their calculated illuminance values (Option2)	Lighting analysis report
Floor plans highlighting regularly occupied spaces (for Healthcare, regularly occupied perimeter area)	Geometry plan from BIM model
List of glare-control devices for all windows with their control mechanism	A schedule generated from BIM tool

Table16. Integration framework of BIM and LEED IEQ credit Daylight

Chapter 6. Case study

In this report, the sample architecture model from Revit 2014 is researched as the case study. It is a three-storey office building with 4213m² floor area. The location is set in Hamburg, Germany.

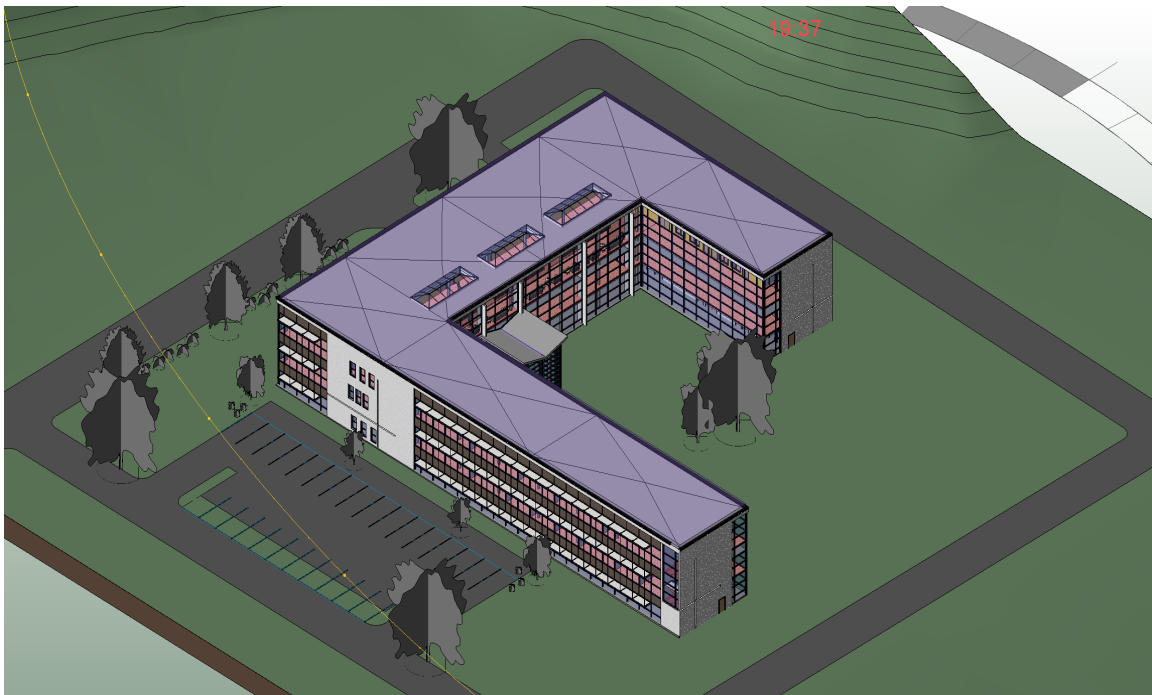


Figure9. Sample architecture 3D model from Revit 2014

The following additional alterations are done to the model:

- All the materials used in the building are defined in detail in LCA tool Tally, and communicated back to the Revit model
- Spaces are created and defined
- Room function is specified and customized to make energy analysis accurate
- More opening are added to the opaque walls
- Plumbing fixtures (urinals, toilets, sinks) are added to the model

6.1 Water Efficiency

WE Prerequisite Indoor Water Use Reduction WE Credit Indoor Water Use Reduction

By adding plumbing appliance and fixtures into the model, it is possible to create the plumbing

fixture schedule from Revit. The detail level of the information depends on how much data is input in the model while defining the properties of the fixtures.

<Plumbing Fixture Schedule>							
A	B	C	D	E	F	G	H
Family	Family and Type	LEED Fixture Baseline Rate (l/gf)	LEED Fixture Family Name	LEED Fixture Installed Rate (l/gf)	LEED Fixture Type Name	LEED Total Daily Uses	Manufacturer
M Urinal-Wall-3D	M Urinal-Wall-3D	3.8	Urinal	3	Urinal		
M Urinal-Wall-3D	M Urinal-Wall-3D	3.8	Urinal	3	Urinal		
M Urinal-Wall-3D	M Urinal-Wall-3D	3.8	Urinal	3	Urinal		
M Sink-Round-2D	M Sink-Round-2D	1.9	Faucet	1.6	Public lavatory faucet		
M Sink-Round-2D	M Sink-Round-2D	1.9	Faucet	1.6	Public lavatory faucet		
M Sink-Round-2D	M Sink-Round-2D	1.9	Faucet	1.6	Public lavatory faucet		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(male)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(male)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(female)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(female)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(female)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(female)		
M Toilet-Commercial-Wall-2D	M Toilet-Commercial-Wall-2D: 380mm Seat H	6	Toilet	4.5	Toilet(female)		

Table17. Plumbing fixture schedule from Revit

LEED required documentation	Predicted BIM Integration	Integration Result
Alternative water narrative	None	
Product cut sheets, manufacturers' information	By adding the water fixtures and detailed product information into the model, it is possible to create a schedule of installed appliance in the BIM model	Possible
Indoor water use calculator	Possibility of integrating the calculator into BIM tool. Information of occupancy and flush rate of appliance will be extracted directly from BIM model to complete the calculator.	Partly possible (No integration of the calculator and BIM tool. It is required to complete the calculator manually by acquiring information of occupancy and flush rate of appliance from BIM model)

Table18. Integration framework of BIM and LEED WE credit Indoor Water Use Reduction

6.2 Energy and Atmosphere

EA Prerequisite Minimum Energy Performance

EA Credit Optimize Energy Performance

When the BIM model is already created in Revit, the energy simulation tool that supported by Green Building Studio (GBS) can be used to analyze the energy consumption of the building. It is necessary to do the initial energy set up of the model. Information like project location, basic HVAC system, fenestration-wall ratio etc. should be given. Besides the energy simulation of the designed model, GBS also provides analysis of 37 default alternative designs, including the design in compliance with the requirements about baseline model in ASHRAE 90.1-2010 (Autodesk, 2014).

Basically, there are three ways in Revit to run energy simulation.

1. Based on conceptual masses.

When a simulation is carried out based on the conceptual masses, a simple model without detailed building information like rooms, stairway etc. is enough. Sometimes greater geometric complexity does not necessarily result in greater accuracy during analysis (Autodesk, 2015).

2. Based on building elements

Thermal properties of each building elements are considered into the simulation by specifying the material.

3. Heating and cooling loads

In order to get accurate result, it is required to have precise, complete building data about building type, spaces type, construction type, operation schedule etc.

It can be noticed that the above three simulation methods differentiate themselves in the level of detail and accuracy. More necessary input will yield more precise output.

In this case study, the following steps are followed to run a relatively accurate simulation:

Basic Setting:

- Building Location

When the project location is inserted, it is also possible to choose the nearest weather station near the project site from the available google map. These weather stations can all provide weather data based on 30-year averages.

- Building Type

When the building type is specified, Revit will automatically provide a default setting for the entire building. A typical operation schedule based on usage is assumed for the model. The default setting in Autodesk Revit for office building is shown below.

Office	
Parameter	Default Value
Occupancy Schedule	Common Office 8am-5pm
Lighting/Equipment Schedule	Office Lighting 6am-11pm
People/100m ²	3.5
People Activity Level	Standing, Light work, Walking
People Sensible Heat Gain (W/person)	73
People Latent Heat Gain (W/person)	59
Lighting Load Density (W/m ²)	10.76
Equipment Load Density (W/m ²)	13.99
Electrical Equipment Radiant Percentage	0.3
Carpet (Y/N)	Y
Condition Type	Heated and Cooled

Table19. The default setting of assumptions used during energy analysis for office building in Revit (Adapted from Building Type Data from Autodesk Revit 2014) (Autodesk, 2014)

- HVAC system

A basic HVAC system is chosen for the building.

Detailed Setting:

- Building construction

Thermal properties for building elements like floors, walls, and roofs are added to the model to enable a more accurate analysis.

- Space properties

This step is essential to refine the energy model. Even though an assumption of the operation schedule is already given in the default setting according to the building type, it doesn't reflect the situation in real project, which is normally more complicated. For each space and zone in the building, they may have different function, therefore distinctive heating, cooling and lighting schedule. These parameters can be customized to specify the default building type setting.

LEED required documentation	Predicted BIM Integration	Integration Result
ASHRAE 90.1-2010 Appendix G energy modeling inputs (Baseline model)	Based on the designed BIM model, energy simulation can apply the ASHRAE 90.1 defaults to the project directly	Partly possible (direct energy simulation result from the baseline model can be generated, but detailed energy inputs of the baseline model is not available).
Input and output reports from modeling software	Energy analysis report	Possible
Target Finder results and summary	The information from energy analysis report can be used	Possible
Energy consumption and demand for each building end use and fuel type	Energy analysis report	Possible
Fuels rates	Calculation based on the energy analysis report	Possible

Table20. The list showing how Revit and Green Building Studio can support the documentation required by LEED energy performance credit

6.3 Material and Resources

MR Credit Building Life-Cycle Impact Reduction

The LCA tool Tally is used here to conduct the whole building life cycle assessment. Tally is an add-in for Revit, and uses GaBi database provided by “thinkstep” (PE International

before). Currently the only database available is North American specific, however thinkstep is working on creating databases for other regions. There is currently no timeline as for when that would come online. Furthermore it is not possible to use any other LCA database with Tally as the database is sealed for quality assurance reasons.

Being the first step of the assessment, Tally generates a list of the materials used in the building, according to the Revit category structure. The material take-off function in Revit is also used here to create a quantity take-off list, to compare the materials generated by Revit and by Tally, to check and ensure the accuracy. At first, nearly all the materials are shown with grey bullets because of not being recognized by Tally. They will turn green when all the materials are defined with proper material from Tally database. During definition, the following aspects are to be considered (KT Innovations, 2014):

- Service life: an LCA for this LEED credit uses an assumed building service life of 60 years. If the material's life cycle is not the same as the building, and should be replaced periodically, the life cycle of certain material should be defined manually if it is not the same as default.
- Take-off method: the method of how the material is supposed to be calculated, by area, volume, length etc.
- Quantity of the material: thickness, length etc. For certain materials that can not be measured by Tally, these parameters can be defined manually depending on how the materials are supposed to be calculated in Tally.

For certain material like concrete, it is also possible to customize the material by defining the concrete type (density or solid percentage) and reinforcement type, to make the material definition represent exactly the substances used in the proposed building. On the other hand, the materials that have no environmental impacts, like vapor or airspace, can be simply defined as dummy material. For materials like finishing, carpet or membrane roofing etc., which cannot last for the whole building life, and need to be replaced periodically, a specific life span should be given in Tally. For instance, if the building life cycle is set to be sixty years, and the life span of mortar is fifteen years, then for the whole building life cycle assessment, the cradle to grave life cycle of the material mortar will be calculated three ($60/15-1=3$) times.

When the LCA of the design building is conducted, then a few alterations can be done to create the baseline building to carry out the comparison according to LEED requirements. In this case one modification is made: concretes (in proposed design) with 50% fly ash are changed to normal concrete. Accordingly, the LCA results differentiate as well, and better life cycle performance is achieved by the proposed design.

LEED required documentation for Option4	Predicted BIM Integration	Integration Result
Description of LCA assumptions, scope, and analysis process for baseline building and proposed building	Report (including Calculation Methodology, Glossary of LCA Terminology) from LCA tool, which can extract the material information from the BIM model	Possible
Life-cycle impact assessment summary showing outputs of proposed building with percentage change from baseline building for all impact indicators	Report from LCA tool, which can extract the material information from the BIM model	Possible

Table21. The list showing how Tally can support the documentation required by LEED credit Building Life-Cycle Impact Reduction Option4

MR Credit Building Product Disclosure and Optimization - Environmental Product Declarations

The process of generating required documentation for this credit relies closely on the LCA report from Tally. At the end of Tally LCA report, a summary of all materials is provided with name, description, life cycle inventory, manufacturing scope, and end of life scope, which offers the possibility of completing the spreadsheet calculator (Table22) by seeking for the products with EPD in the metadata (Figure10).

Paint, exterior acrylic latex, Acryl-Fassadenfarbe, EPD - Brillux	246.9 kg
Used in the following Revit families: Parapet Wall	246.9 kg
Used in the following Tally entries: Autoclaved aerated concrete block (AAC)	
Description: The primers and facade paints are applied as coatings and bonding agent for mineral and organic substrates as well as on wood and metal surfaces for outdoor use. EPD representative of German (DE) conditions.	
Life Cycle Inventory: Acrylic paint	
Manufacturing Scope: Cradle to gate	
End of Life Scope: Includes 100% disposal to landfill as plastic waste	
Entry Source: DE: Primers and facade paints, Acryl-Fassadenfarbe - Brillux (A1-A3) PE-EPD (2010)	

Figure10. Example of one building product with EPD from the metadata list in Tally report

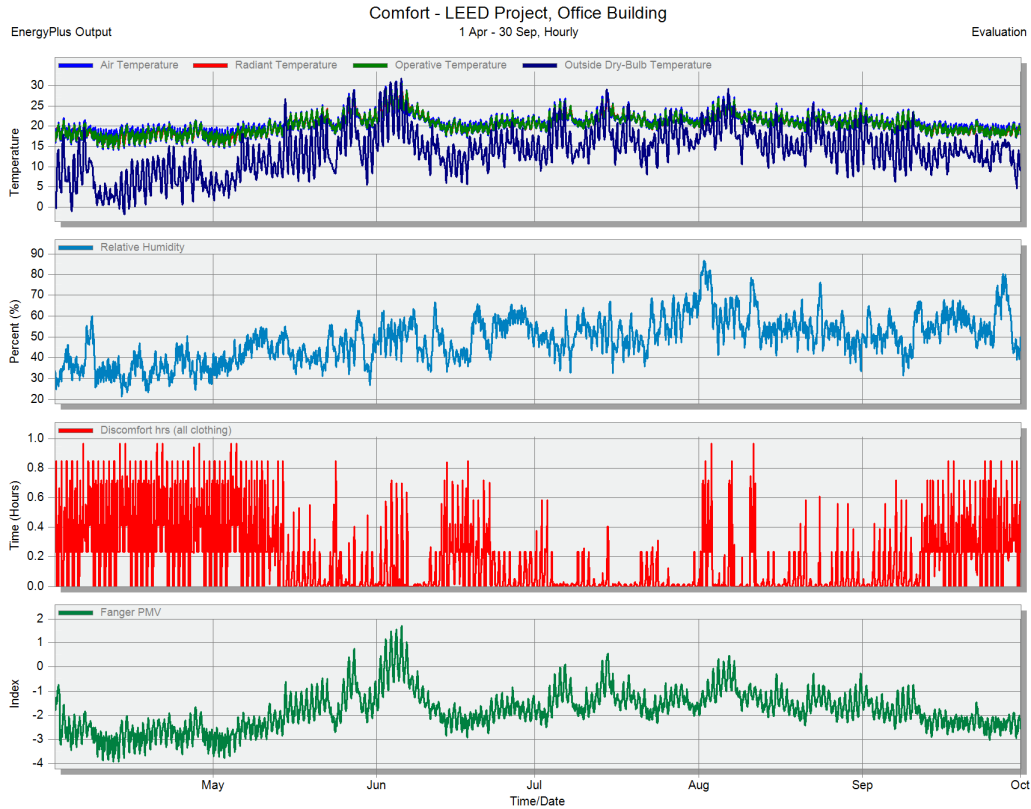


Figure11. Thermal simulation output showing the temperature, humidity, discomfort hours, and PMV value for summer hours

Date/Time	Relative Humidity	Fanger PMV	Air Temperature	Radiant Temperature	Operative Temperature	Discomfort hrs (all clothing)	Outside Dry-Bulb Temperature
Unit	%		Celsius degree	Celsius degree	Celsius degree	hrs	Celsius degree
2014/4/1 1:00	33.75	-1.50	16.82	17.61	17.22	0.23	2.33
2014/4/1 2:00	33.44	-1.62	16.40	17.26	16.83	0.23	1.00
2014/4/1 3:00	33.09	-1.70	16.10	16.95	16.53	0.23	0.68
2014/4/1 4:00	32.76	-1.77	15.84	16.68	16.26	0.23	0.38
2014/4/1 5:00	28.06	-1.66	17.90	16.61	17.25	0.23	0.08
2014/4/1 6:00	26.69	-1.47	18.32	16.78	17.55	0.23	-0.30
2014/4/1 7:00	24.94	-1.36	19.23	17.28	18.26	0.85	-0.03
2014/4/1 8:00	24.81	-1.25	19.40	17.79	18.59	0.85	2.20
2014/4/1 9:00	28.58	-1.37	17.45	17.63	17.54	0.00	5.53
2014/4/1 10:00	30.06	-1.54	17.10	17.47	17.29	0.00	8.28
2014/4/1 11:00	30.45	-1.50	17.27	17.72	17.49	0.00	9.20
2014/4/1 12:00	30.00	-1.35	17.88	18.27	18.07	0.00	10.43
2014/4/1 13:00	29.77	-1.14	18.44	18.96	18.70	0.00	12.08
2014/4/1 14:00	29.61	-1.01	18.84	19.48	19.16	0.00	13.33
2014/4/1 15:00	29.46	-0.91	19.09	19.86	19.47	0.00	12.33
2014/4/1 16:00	29.08	-0.87	19.36	20.07	19.72	0.00	13.78
2014/4/1 17:00	26.56	-0.77	20.84	20.18	20.51	0.00	14.25
2014/4/1 18:00	26.32	-0.73	20.93	20.12	20.53	0.42	13.68
2014/4/1 19:00	27.69	-0.84	20.16	19.56	19.86	0.49	12.30
2014/4/1 20:00	28.58	-0.95	19.82	19.18	19.50	0.49	10.03
2014/4/1 21:00	29.16	-0.99	19.58	18.96	19.27	0.63	8.20
2014/4/1 22:00	29.56	-1.05	19.34	18.81	19.07	0.67	7.43
2014/4/1 23:00	30.82	-1.15	18.60	18.43	18.52	0.23	6.03

Table24. Part of the detailed thermal simulation output showing the various values of each hour for April 1st

Based on the simulated data and the average value, the Center for the Build Environment (CBE) Thermal Comfort Tool for ASHRAE-55 is used to perform the required PMV and PPD calculation. It can be seen from the result that the first thermal design cannot provide proper comfort level for the occupants according to ASHRAE standard. When the dressing code is eased and the value “Clothing level” is set as 1.1, which means occupants are allowed to adjust clothing by demand, the comfort level is reached (see Figure12). Referring to Figure12, the results also conform to ISO 7730-2005 and EN 15251-2007 standards on thermal comfort. There are some other simulation tools (e.g. IES Virtual Environment) that can directly generate LEED required documentation based on the simulation results. IES VE has also developed a plug-in for Revit, which makes the whole process more efficient.

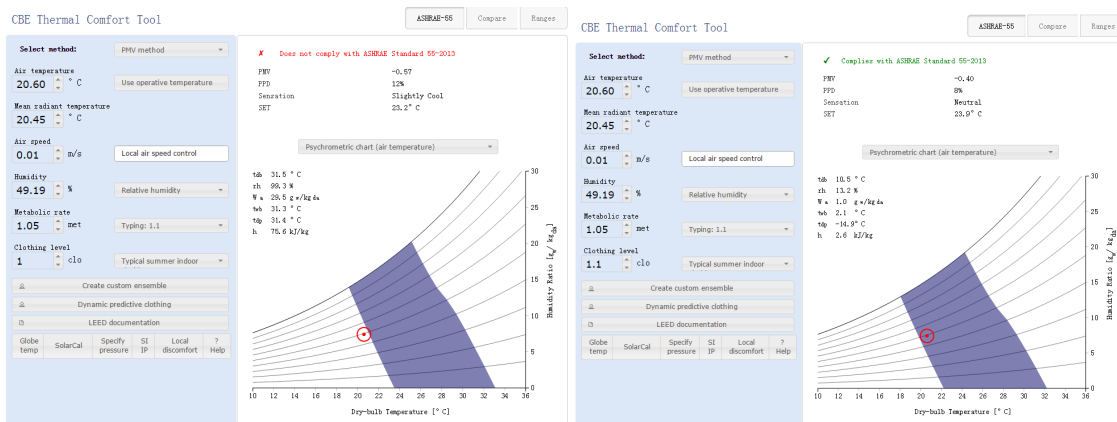


Figure12. First and second thermal comfort design results according to ASHRAE 55-2013

LEED Required Documentation	Predicted BIM Integration	Integration Result
Option1		
Description of weather data used to determine operative temperatures, relative humidity, outdoor temperatures	When the location of the project is defined in the BIM model, corresponding weather data will be extracted from the database, and be displayed within in the output report	Possible
Plots or calculation results verifying that design parameters meet ASHRAE Standard 55–2010 for 80% acceptability (e.g., psychrometric chart; PMV or PPD calculations; ASHRAE Thermal Comfort Tool results; or predicted worst-case indoor conditions for each month)	Based on the basic information (geometric and material and HVAC etc.) of the BIM model, air temperature, radiant temperature, air velocity and humidity can be calculated by the BIM simulation software. Afterwards, by manually inputting the dressing code and metabolic rate of occupants, the comfort level can be calculated with the demanded calculation methods.	Possible

Option2		
Documentation to verify thermally conditioned spaces meet ISO 7730 or EN 15251, as applicable	Based on the basic information (geometric and material and HVAC etc.) of the BIM model, air temperature, radiant temperature, air velocity and humidity can be calculated by the BIM simulation software. Afterwards, by manually inputting the dressing code and metabolic rate of occupants, the comfort level can be calculated with the demanded calculation methods.	Possible

Table25. The list showing how Designbuilder and CBE Thermal Comfort Tool can support the documentation required by LEED credit Thermal Comfort

IEQ Credit Daylight

In this case, option2 is chosen to fulfill the LEED requirements with the Revit lighting analysis add-in. The threshold for assessment is 300lux-3000lux. Two simulations are run respectively for 9am and 3pm on September 17th. When the illuminance simulation is done, a final result with the percentage of qualified spaces where can reach the required daylight level will show up. More detailed information about the result consists of two parts:

- 1) The illuminance value of each building level and each space

<_Lighting Analysis Floor Schedule>														
LEED v4 EQc7 opt2Whole Building Results - 9am: 54% within, 3pm 67% within														
9/17 9am GHI: 281, DNI: 478, DHI: 78 W/m2														
9/17 3pm GHI: 334, DNI: 529, DHI: 82 W/m2														
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Name	Floor Area Included in Daylighting	Total Floor Area	9am threshold results						3pm threshold results					
			within threshold %	above threshold Area	within threshold %	above threshold Area	below threshold %	below threshold Area	within threshold %	above threshold Area	below threshold %	below threshold Area		
01 - Entry Level	1564 m ²	1564 m ²	57	896 m ²	21	325 m ²	22	343 m ²	65	1022 m ²	11	166 m ²	24	377 m ²
02 - Floor	1608 m ²	1608 m ²	53	850 m ²	20	318 m ²	27	439 m ²	63	1010 m ²	9	143 m ²	28	454 m ²
03 - Floor	1475 m ²	1475 m ²	51	749 m ²	31	453 m ²	19	273 m ²	72	1063 m ²	12	174 m ²	16	239 m ²

Table26. Simulation result showing the illuminance value of each floor level in detail

<_Lighting Analysis Room Schedule>																	
LEED v4 EQc7 opt2Whole Building Results - 9am: 54% within, 3pm 67% within																	
9/17 9am GHI: 281, DNI: 478, DHI: 78 W/m2																	
9/17 3pm GHI: 334, DNI: 529, DHI: 82 W/m2																	
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
wtwt	Name	Number	Area	Include In Daylighting	Automated Shades	9am threshold results						3pm threshold results					
						within threshold %	Area	above threshold %	Area	below threshold %	Area	within threshold %	Area	above threshold %	Area	below threshold %	Area
01 - Entry Level Vest	101	41 m ²	✓	☐	78	32 m ²	0	0 m ²	22	9 m ²	100	41 m ²	0	0 m ²	0	0 m ²	
01 - Entry Level Lobby	102	327 m ²	✓	☐	76	247 m ²	0	0 m ²	24	80 m ²	79	259 m ²	0	0 m ²	21	68 m ²	
01 - Entry Level Cafeteria	121	147 m ²	✓	☐	90	132 m ²	3	4 m ²	8	11 m ²	65	96 m ²	28	40 m ²	8	11 m ²	
01 - Entry Level Prep/Dish	122	22 m ²	✓	☐	33	7 m ²	0	0 m ²	67	15 m ²	33	7 m ²	0	0 m ²	67	15 m ²	
01 - Entry Level Dry Storage	124	8 m ²	✓	☐	0	0 m ²	0	0 m ²	100	8 m ²	0	0 m ²	0	0 m ²	100	8 m ²	
01 - Entry Level Electrical	125	6 m ²	✓	☐	0	0 m ²	0	0 m ²	100	6 m ²	0	0 m ²	0	0 m ²	100	6 m ²	
01 - Entry Level Conference	123	42 m ²	✓	☐	20	8 m ²	0	0 m ²	80	33 m ²	20	8 m ²	0	0 m ²	80	33 m ²	
01 - Entry Level Office	127	15 m ²	✓	☐	75	12 m ²	0	0 m ²	25	4 m ²	75	12 m ²	0	0 m ²	25	4 m ²	
01 - Entry Level Admin	126	16 m ²	✓	☐	0	0 m ²	0	0 m ²	100	16 m ²	0	0 m ²	0	0 m ²	100	16 m ²	
01 - Entry Level Storage	128	10 m ²	✓	☐	0	0 m ²	0	0 m ²	100	10 m ²	0	0 m ²	0	0 m ²	100	10 m ²	
01 - Entry Level Toilet	129	6 m ²	✓	☐	0	0 m ²	0	0 m ²	100	6 m ²	0	0 m ²	0	0 m ²	100	6 m ²	
01 - Entry Level Stair	130	19 m ²	✓	☐	25	5 m ²	50	9 m ²	25	5 m ²	25	5 m ²	0	0 m ²	75	14 m ²	
01 - Entry Level Corridor	131	55 m ²	✓	☐	0	0 m ²	100	55 m ²	0	0 m ²	100	55 m ²	0	0 m ²	0	0 m ²	
01 - Entry Level Sprinkler	119	9 m ²	✓	☐	0	0 m ²	0	0 m ²	100	9 m ²	0	0 m ²	0	0 m ²	100	9 m ²	
01 - Entry Level Electrical	118	17 m ²	✓	☐	0	0 m ²	0	0 m ²	100	17 m ²	0	0 m ²	0	0 m ²	100	17 m ²	
01 - Entry Level Instruction	117	49 m ²	✓	☐	53	26 m ²	0	0 m ²	47	23 m ²	47	23 m ²	53	26 m ²	0	0 m ²	
01 - Entry Level Lounge	120	41 m ²	✓	☐	100	41 m ²	0	0 m ²	0	0 m ²	100	41 m ²	0	0 m ²	0	0 m ²	
01 - Entry Level Conference	116	32 m ²	✓	☐	40	13 m ²	0	0 m ²	60	19 m ²	50	16 m ²	50	16 m ²	0	0 m ²	
01 - Entry Level Office	115	127 m ²	✓	☐	65	82 m ²	35	44 m ²	0	0 m ²	38	48 m ²	63	79 m ²	0	0 m ²	
01 - Entry Level Stair	114	19 m ²	✓	☐	0	0 m ²	0	0 m ²	100	19 m ²	0	0 m ²	0	0 m ²	100	19 m ²	
01 - Entry Level Electrical	112	7 m ²	✓	☐	0	0 m ²	0	0 m ²	100	7 m ²	0	0 m ²	0	0 m ²	100	7 m ²	
01 - Entry Level Lounge	111	38 m ²	✓	☐	45	17 m ²	36	14 m ²	18	7 m ²	18	7 m ²	0	0 m ²	82	31 m ²	
01 - Entry Level Men	110	14 m ²	✓	☐	0	0 m ²	0	0 m ²	100	14 m ²	0	0 m ²	0	0 m ²	100	14 m ²	
01 - Entry Level Women	109	13 m ²	✓	☐	0	0 m ²	0	0 m ²	100	13 m ²	0	0 m ²	0	0 m ²	100	13 m ²	
01 - Entry Level Corridor	107	137 m ²	✓	☐	94	129 m ²	0	0 m ²	6	9 m ²	88	120 m ²	3	4 m ²	9	13 m ²	
01 - Entry Level Office	108	89 m ²	✓	☐	47	42 m ²	53	48 m ²	0	0 m ²	90	81 m ²	0	0 m ²	10	9 m ²	
01 - Entry Level Office	106	48 m ²	✓	☐	45	22 m ²	55	26 m ²	0	0 m ²	70	34 m ²	0	0 m ²	30	14 m ²	
01 - Entry Level Office	105	97 m ²	✓	☐	30	29 m ²	70	68 m ²	0	0 m ²	90	87 m ²	0	0 m ²	10	10 m ²	
01 - Entry Level Office	104	48 m ²	✓	☐	40	19 m ²	60	29 m ²	0	0 m ²	73	35 m ²	0	0 m ²	27	13 m ²	
01 - Entry Level Conference	103	47 m ²	✓	☐	40	19 m ²	60	28 m ²	0	0 m ²	93	44 m ²	0	0 m ²	7	3 m ²	
01 - Entry Level Stair	132	19 m ²	✓	☐	75	14 m ²	0	0 m ²	25	5 m ²	25	5 m ²	0	0 m ²	75	14 m ²	

Table27. Simulation result showing the illuminance value of each space in detail

2) The contour map showing the daylight distribution in each space of the building

It is easy to notice from the map that some spaces on this floor level are totally under threshold, which indicates the necessity of further modification about the design of openings. According to LEED requirement, the daylight level in at least 75% of the area should be within the threshold. At first sight of the simulation result, it seems that the building is not possible to get the credit. However, two additional factors should be considered:

- Not all the spaces are regularly occupied spaces
- Automated shadings can be considered for necessary spaces for glare control

In the lighting analysis room schedule, it is possible to exclude the following non-regularly occupied spaces from the daylight analysis.

- Corridors
- Electrical
- Stair
- Storage
- Toilet

Analysis Run	Modification
1	Original
2	Some opening are added to the spaces where the illuminance level is below threshold
3	Automated shades are added to the spaces where the illuminance level is above threshold, non-regularly occupied spaces are excluded

Table28. Modification history of the three daylight simulation runs

Once automated shades are added to a certain space in Revit, the tool will assume automatically that there will be no possibility to experience glare pollution over 3000 lux any more in this space, which is reasonable because the automated shades work always together with building sensors to adjust the shades to avoid direct sunlight for the occupants (Selkowitz & LEE, 2004). In the interior space, indirect sunlight can normally not reach extremely high illuminance value.

The change of the simulation results follows the modification of the model and the parameters:

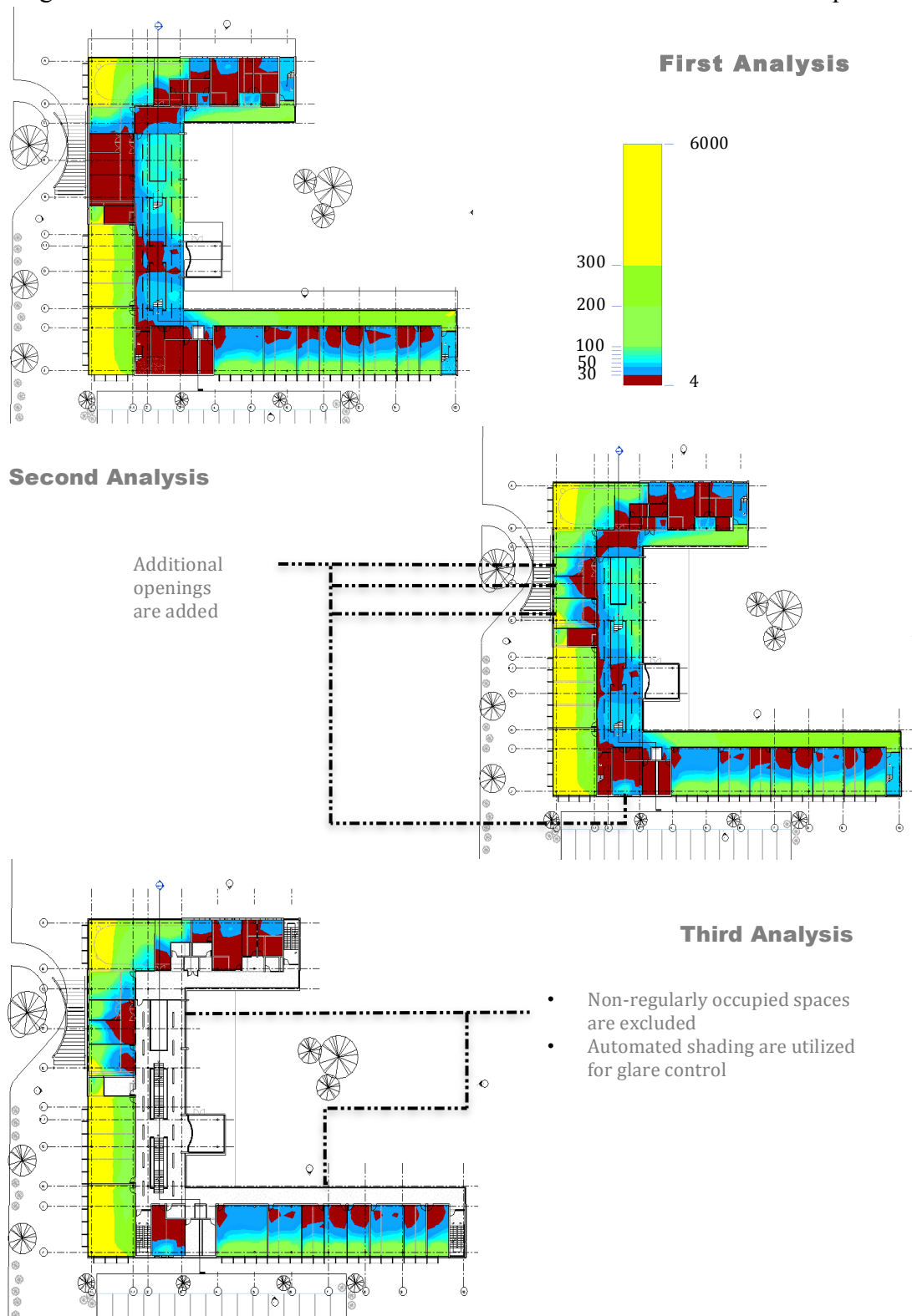


Figure13. Contour map showing the daylight distribution in all spaces on the second building floor level at 3pm on September 17th, demonstrating the results of three modifications

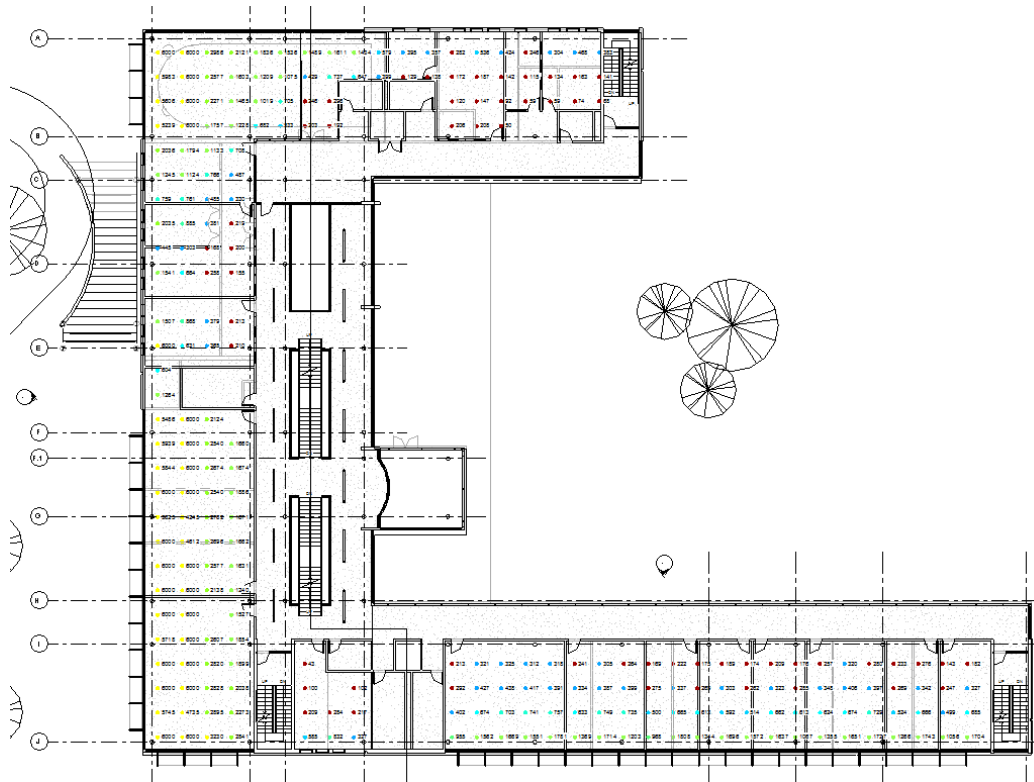


Figure 14. Geometric plot map of daylighting analysis of the second building floor level at 3pm on September 17th, showing the illuminance value of each spot

After the third fine-tuning of the design, the expected result comes out.

<_Lighting Analysis Floor Schedule>														
LEED v4 EQc7 opt2Whole Building Results - 9am: 78% within, 3pm 79% within														
9/17 9am GHI: 281, DNI: 478, DHI: 78 W/m2														
9/17 3pm GHI: 334, DNI: 529, DHI: 82 W/m2														
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Name	Floor Area Included in Daylighting	Total Floor Area	9am threshold results						3pm threshold results					
			within threshold %	Area	above threshold %	Area	below threshold %	Area	within threshold %	Area	above threshold %	Area	below threshold %	Area
01 - Entry Level	1185 m ²	1564 m ²	83	978 m ²	0	0 m ²	17	207 m ²	81	965 m ²	0	0 m ²	19	219 m ²
02 - Floor	938 m ²	1608 m ²	72	672 m ²	1	8 m ²	27	258 m ²	73	681 m ²	3	30 m ²	24	227 m ²
03 - Floor	972 m ²	1475 m ²	79	771 m ²	2	15 m ²	19	186 m ²	83	811 m ²	0	4 m ²	16	156 m ²

Figure 15. The detailed lighting analysis result of each building floor for the third analysis

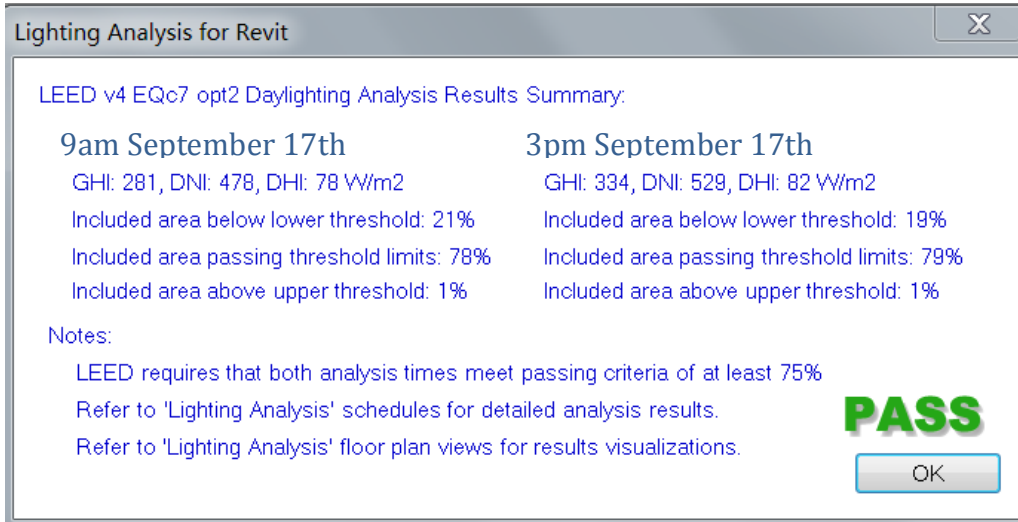


Figure16. The daylighting analysis result summary from Revit in compliance with LEED Daylight credit

In order to prepare the submittals for LEED, various documents generated from Revit can be used:

LEED required documentation for Option 2 simulation	Predicted BIM Integration	Integration Result
Geometric plots from simulations	By extracting building information (location, orientation, openings) from BIM model, lighting report can be generated after the analysis is completed	Possible
Narrative or output file describing daylight simulation program, simulation inputs, and weather file	Daylight simulation tool	None (a template document should be created)
List of compliant spaces with their calculated illuminance values	Lighting analysis report	Possible
Floor plans highlighting regularly occupied spaces (for Healthcare, regularly occupied perimeter area)	Geometry plan from BIM model	Possible (Lighting analysis contour map)
List of glare-control devices for all windows with their control mechanism	A schedule generated from BIM tool	Possible

Table29. The list of documentation that can be provided from Revit and used as submittal for applying LEED Daylight credit

Chapter 7. Conclusion

It is possible to integrate BIM with LEED certification system, but currently additional work is still necessary to make the workflow fluent. The process of generating the documents required by LEED from the BIM model is not constantly seamless and a bit disconnected from BIM modeling tool. From the case study, it can be seen that BIM contributes to documentation process of different credits on various levels. Table 30 shows the “BIMability” of the discussed credits, which describes the weights of the credits in the whole LEED certification system and also the integration level with BIM. Based on the “BIMability” value, it can be indicated that which credits are relatively important in LEED certification system, and also can be incorporated with BIM with relative few obstacles. However, there are still gaps between theoretical feasibility and practical achievement. The development of the integration framework has still obstacles on process, which may be contributed by limitation of BIM tool functionality and lack in understanding LEED certification scheme.

LEED Credit	Credit weight	BIM Integration level	BIMability
WE Credit Indoor Water Use Reduction	5.45%	**	10.9
EA Credit Optimize Energy Performance-Option1	16.36%	****	65.44
MR Credit Building Life-Cycle Impact Reduction-Option4	2.73%	*****	13.65
MR Credit Building Product Disclosure and Optimization - Environmental Product Declarations-Option1	0.91%	***	2.73
IEQ Credit Thermal Comfort	0.91%	*****	4.55
IEQ Credit Daylight-Option2	2.73%	*****	13.65

Table30. Comparison of credit weight and BIM integration level of different LEED credits

Despite the development of BIM-LEED integration framework, USGBC/GBCI does not approve any specific simulation tools or analysis software, so it should be considered that the BIM tools used in case study part are neither affiliated with nor endorsed by USGBC (USGBC, 2014). However for energy performance, LEED requires to use the DOE-2 hourly energy simulation engine, through which the accepted modeling tools can be got a sense. There is no guarantee that the targeted LEED credits are sure to be achieved with these tools. However, when properly used, they would contribute to generating LEED required submittals to a certain level.

Chapter 8. Outlook and Suggestions on Future Research

When we start with the attitude of “Nothing is impossible” , there is still a long way to go until “Everything is easy”. Comparing with design teams, green building consultants are currently playing the main roles in green building industry. When a project is “labeled” as a “green building”, it will normally attract attention from public and also be highly complimented from the administration department. However, most design and construction teams still continue using the conventional tools and process. This forms an interesting phenomenon in green building industry: active research teams, wide public attention and laggard design teams, who are actually the key part of the whole process. Despite that the research teams are relatively active in various new topics and leading the new trend, project design teams fall behind in integrating the new thoughts and techniques. Without the successful transfer from theory to practice with the cooperation of the design teams, no achievement in research can be utilized and popularized, and the gap will not be filled. Last but not least, the consultant and certification teams should also improve their competibility to be qualified for future tasks when the design teams catch up and the gaps are filled.



Figure17. Green building industry current situation

Suggestion on future research based on this study:

- How to build up the training framework for competent specialists in BIM-Green Building Certification;
- The concerns of BIM development;
- Further development on BIM functionalities, in order to integrate with more green building certification credits;
- The development of administrative regulation and incentives on BIM utilization.

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Appendix

Fixture or Fitting	Baseline (SI units)
Toilet (water closet)	6 lpf
Urinal	3.8 lpf
Public lavatory (restroom) faucets	1.9 lpm at 415 kPa, all others except private applications
Private lavatory faucets	8.3 lpm at 415 kPa
Kitchen faucet (excluding faucets used exclusively for filling operations)	8.3 lpm at 415 kPa
Showerhead	9.5 lpm at 550 kPa per shower stall

Table31. Baseline water consumption of fixtures and fittings

Building Type	Fossil Fuel, Fossil/Electric Hybrid, and Purchased Heat	Electric and Other
Residential	System 1 - PTAC	System 2 - PTHP
Nonresidential and 3 Floors or less and <2322,6 m ²	System 3 - PSZ-AC	System 4 - PSZ-HP
Nonresidential and 4 or 5 Floors and <2322,6 m ² or 5 Floors or less and 2322,6 m ² to 13935m ²	System 5-Packaged VAV with reheat	System 6-Packaged VAV with PFP Boxes
Nonresidential and More than 5 Floors or >13935m ²	System 7- VAV with Reheat	System 8-VAVwith PFP Boxes
Heated Only Storage	System 9-Heating and Ventilation	System 10 - Heating and Ventilation

Table32. Baseline HVAC system types

System No.	System Type	Fan Control	Cooling Type	Heating Type
1. PTAC	Packaged terminal air conditioner	Constant volume	Direct expansion	Hotwater fossil fuel boiler
2. PTHP	Packaged terminal heat pump	Constant volume	Direct expansion	Electric heat pump
3. PSZ-AC	Packaged rooftop air conditioner	Constant volume	Direct expansion	Fossil fuel furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant volume	Direct expansion	Electric heat pump
5. Packaged VAV with Reheat	Packaged rooftop VAV with reheat	VAV	Direct expansion	Hot-water fossil fuel boiler
6. Packaged VAV with PFP Boxes	Packaged rooftop VAV with parallel fan power boxes and reheat	VAV	Direct expansion	Electric resistance
7.VAV with Reheat	VAV with reheat	VAV	Chilled water	Hot-water fossil fuel boiler
8.VAV with PFP Boxes	VAV with parallel fan-powered boxes and reheat	VAV	Chilled water	Electric resistance
9. Heating and Ventilation	Warm air furnace, gas fired	Constant volume	None	Fossil fuel furnace
10. Heating and Ventilation	Warm air furnace, electric	Constant volume	None	Electric resistance

Table33. Baseline System Descriptions