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The Potential of Building Information Modeling in Application Process of G-SEED

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Abstract Given the barriers to implement green building rating systems, Building Information Modeling (BIM) was suggested as an effective solution integrating information into one model and saving substantial time to facilitate certification process. Synergies between BIM and Leadership in Energy and Environment Design (LEED), the most widely used rating system, have been researched for a few decades. This paper demonstrates literature review about the development of integration between BIM and LEED. The research focuses on synergies between BIM and Green Standard for Energy & Environmental Design (G-SEED) in Korea, as one of important strategies to mitigate greenhouse gas emission. The research compares LEED and G-SEED related items based on evaluation contents. The result manifests G-SEED and LEED share many common items in different degrees. Therefore, it is entirely possible for G-SEED and BIM to adapt same developing mode of LEED and BIM. Moreover, the study measures the potential of BIM in application process of G-SEED certification by investigation of credits in LEED and G-SEED can be earned by BIM. The results of paper indicate the documentation support LEED and G-SEED may be prepared directly, semi-directly and indirectly via sustainability analyses software in BIM.

Keywords: LEED, Green Building, G-SEED, Building Information Modeling, Integration

1. INTRODUCTION

Buildings account for more than 35% of global final energy use and nearly 40% of energy-related CO2 emissions, reported by Thibaut Abergel and al. (2017). Moreover, current buildings energy-carbon intensities are hardly to meet ambition limiting temperature raise to 1.5 to 2 degrees Celsius above pre-industrial levels in 21th century. Green building is becoming increasingly desirable, as one of approaches to mitigate enormous impact of building sector on environment.

In order to accelerate green building development, many countries have initiated criteria for green building design and

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Table 1. Comparison of LEED and G-SEED certification system

Classification	LEED v4 for BD+C	G-SEED 2016-2
Country	U.S.	Republic of Korea
Year Announced	2014	2018
Target	New construction	New non-residential building
Institution	U.S. Green Building Council (USGBC)	Ministry of Land, Infrastructure, and Transport and the Ministry of Environment
Evaluation categories	Location and Transportation (LT)	Land use and Transportation(LT)
	Sustainable Sites (SS)	Energy and Pollution(EP)
	Water Efficiency(WE)	Materials and Resources(MR)
	Energy and Atmosphere (EA)	Water(W)
	Materials and Resources (MR)	Management(M)
	Indoor Environmental Quality (EQ)	Ecology(E)
	Innovation (IN)	Indoor Environment Quality(EQ)
	Regional Priority (RP)	Innovative Design(ID)
Items	12(Prerequisite) 47(Credit)	44(score) 10(Extra)
Total score	110	>106
Calculation	Credits	Weighting multiply distributed score
Certification grade	LEED Certified(40-50), LEED Silver(50-59), LEED Gold(60-79), LEED Platinum(80-110).	Ordinary(50-59) Green Level 4; Good(60-69) Green Level 3; Excellent(70-79) Green Level 2; Best(>80) Green Level 1.

construction. Such as United States' LEED; Republic of Korea's G-SEED; United Kingdom's BREEAM, or Building Research Establishment Environmental Assessment Method; Australia's Green Star; Japan's Comprehensive Assessment System for Building Environmental Efficiency, etc. These criteria can be categorized as performance-based rating system and prescriptive rating system. Performance-based rating system provides assessment for completed buildings and prescriptive rating system relies on simulation and sustainable design standards in pre-design stage.

According to U.S. Green Building Council (USGBC), LEED is the most widely used green building rating system in the world with more than 93,000 projects participating in LEED across 167 countries and territories. LEED is available for virtually all building types. The LEED v4 BD+C rating system is the newest version since LEED was originally introduced in 2000 by USGBC. It contains 8 categories as follows: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority. LEED certification includes four levels aggregating 110 credits (prerequisite items are not containing in total credits): 40 to 50 credits for LEED Certified, 50 to 59 credits for LEED Silver, 60 to 79 credits for LEED Gold, 80 to 110 credits for LEED Platinum.

G-SEED was initiated in 2002 by the Ministry of Land, Infrastructure, and Transport and the Ministry of Environment. G-SEED is also one of the important regulations in Green Growth strategy launched by Korean Energy Agency to accomplish the plan that reduce its greenhouse gas emissions by 37% from the business-as-usual (BAU, 850.6 MtCO2eq) level by 2030 across all economic sectors (Korean Energy Agency 2018).

The G-SEED comprises of 8 categories: Land use and Transportation; Energy and Pollution; Materials and Resources; Water; Management; Ecology; Indoor Environment Quality; Innovative Design. There are four levels in New Constructed Non-residential Building: 50 to 59 points for Green Level 4; 60 to 69 points for Green Level 3; 70 to 79 points for Green Level 2; above 80 points for Green Level 1.

These green building rating systems, in spite of providing a viable framework to achieve sustainable design and construction, confronting problems containing the financial issue, administrative burden due to complicated progress and time-cost feature because of countless documentation, to a certain extent, encumber stakeholders from implementing rating systems. Furthermore, Navarro (2009) pointed out 3 formidable challenges LEED was facing: First, many designers prioritize lowest-cost credits to addressing environmental impact. Second, LEED creates possibility that although buildings possess a high level of performance, neglecting other aspects of sustainability performance. Finally, LEED results in a gap between predicted performance and actual performance. Therefore, in order to simplify and expedite the process of application, achieving lowest-cost credits, instead of traditional methodology, they have to utilize a seamless and integrated methodology. Traditional 2-Dimensional CAD (computer-aided design) is no longer capable of supporting huge volumes of data aggregation. Building information modeling arose as a solution to sustainable design and is embraced by AEC industry. Krygiel and Nies (2008) delineated industry best practices of utilizing BIM to plan, design, and construct buildings in compliance with sophisticated performance criteria and regulatory requirements. Lu, Y and al. (2017) pointed out through literature research that green BIM applications could bring benefits to green building assessment (GBA) process by ways of estimating GBA scores, managing application documents, and improving the efficiency.

BIM is defined by Gordon V.R. and Holness, P.E. (2008) as the assembly of a single database of fully integrated and interoperable information that can be used seamlessly and sequentially by all members of the design and construction team and, ultimately, by owners/operators throughout a facility's life cycle. Accordingly, BIM is not a piece of software. It is an integrated database storing all information of building from cradle to grave.

The advantages BIM brought about were utilized by design companies to overcome obstruction existing in implementation of rating system. For instance, Eddy Krygiel and Bradley Nies (2008) put forward that by assembling all information in one BIM model, integrated documents enable members avoid repeating same work redundantly and miscommunication. In addition, materials database substitute adding physical properties by annotation on 2-dimensional CAD drawing with a model containing key data such as R-values, materiality, recyclability and so on, whereby improving accuracy of energy simulation. These abilities are crucial to facilitate process of green building certification. Mah, D and al. (2011) studied house construction CO2 footprint quantification in Canada, alleged that the BIM approach allows for rapid computations of CO2 emissions from house constructions, helping improve planning and decision-making prior to construction and reductions of CO2 emissions.

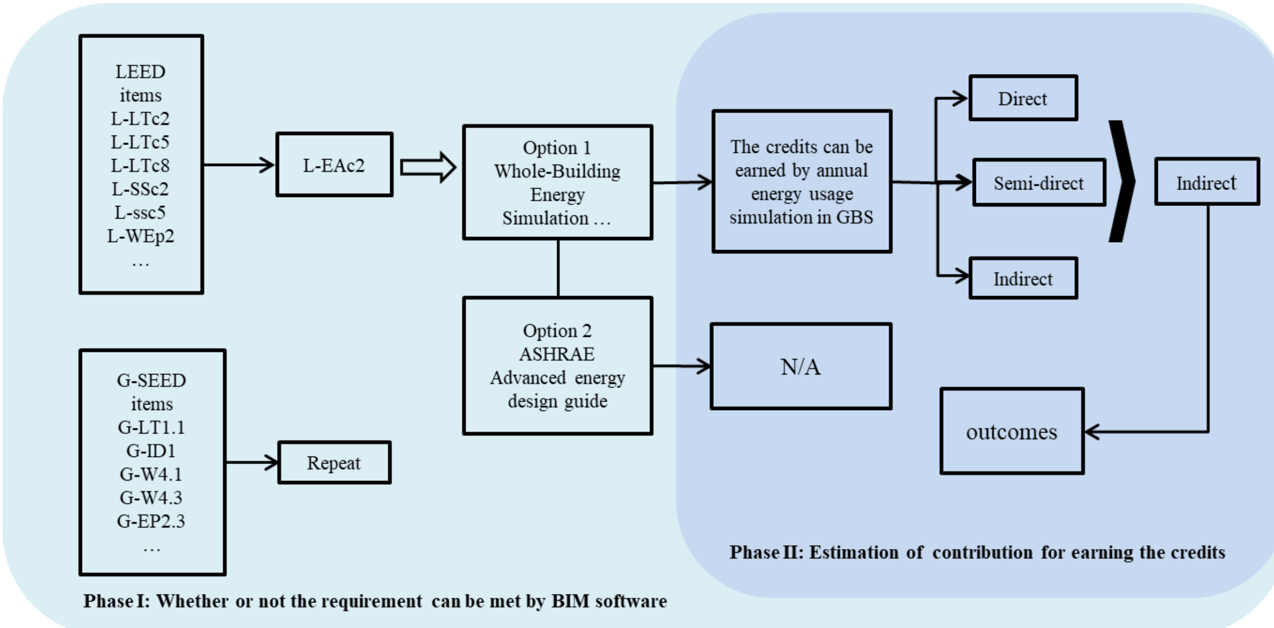
Consequently, companies started to integrate BIM and rating system process and researchers have addressed BIM/LEED synergies. This study will conduct literature review of development of BIM/LEED integration.

In Korea, however, researches about integration BIM and G-SEED are scarce. Although BIM adoption is increasing due to governmental policy and promotion, Seulki Lee and Jungho Yu (2015) confirmed there is still significant difference in BIM adaptation between Korea and United States. This study attempts to find out prospect of synergies between BIM and G-SEED via investigation about integration development between BIM and LEED.

2. PURPOSE OF STUDY, SCOPE AND METHODOLOGY

The purpose of this study is to investigate development of integration between BIM and LEED and measure possibility and feasibility of adapting same mode into G-SEED. The study also demonstrates designers may use BIM system to facilitate application process of G-SEED certification, along with the

Table 2. Workflow of estimating credits can be earned by BIM



potential of BIM in application.

The integration of BIM with LEED certification and G-SEED certification can be recapitulated into single question: What requirements of LEED or G-SEED can be matched up with functionalities the BIM could provide? We have to select representative and available software to represent BIM functionalities. Revit and Green Building Studio are selected in this research. The next step is to generally evaluate each LEED credits and option requirements, investigating whether or not the requirement can be fulfilled by functions that available BIM software possess. The credits that can be obtained in assistance of BIM software are categorized into three levels according to how much degree the BIM can help achieve. Finally, the credits in LEED and G-SEED can be achieved by Revit and GBS are listed and evaluated.

This research specifically focuses on LEED v4 Building Design and Construction (BD+C) rating system and G-SEED rating system for New Constructed Non-residential Building. The research did not investigate financial benefits and deficits of using BIM system. Besides, this study concentrates on Revit and Green Building Studio in BIM. Both are representative in BIM design process.

The study is adopted as follows:

1. Conduct literature review about integration of LEED and BIM system.
2. Comparison of items' evaluation content between G-SEED and LEED.
3. Interacting LEED and G-SEED credits with BIM-based sustainability analyses and exploration of the BIM software to investigate credits can be earned by BIM software.

3. DEVELOPMENT OF SYNERGIES BETWEEN BIM AND LEED

There are a substantial number of scholarly researches on BIM, sustainable design and rating systems. This study divides the development of synergies between BIM and LEED into 5 phases as showed in Table 2.

Companies that realized benefits of BIM in green building design and construction were making assiduous efforts to pursue after synergies between BIM and green building. In 2006, the USGBC inaugurated LEED Online in order to provide support for managing the LEED documentation process. With immanent drawbacks, however, LEED Online undermined the productivity of projects and also made USGBC rethink LEED Online.

At first stage, many researchers tended to test BIM system could be contributory to expedite certification process. Eddy Krygiel and Bradley Nies (2008) stated BIM can aid in sustainable design including building orientation, building massing, daylighting analysis, water harvesting, energy modeling, sustainable materials and site and logistics management. Salman Azhar and al. (2011) built a conceptual framework displaying the relationship between LEED credits and BIM-based sustainability presented by Eddy Krygiel and Bradley Nies (2008). Barnes and Castro-Lacouture (2009) adumbrated possibilities that combining BIM and LEED certification design. Lawrence C. Bank and al. (2010) asserted BIM can be used to improve decision-making in building design.

After introspection about LEED Online, LEED Automation was announced in 2010 by USGBC that collaborates with technology companies to streamline and create capacity for the LEED certification process. Through the program, LEED can interact with third-party technology platforms, thereby facilitating certification process. According to USGBC, LEED Automation takes the green building process to a new level.

More and more researchers attempted to integrate BIM and green building rating systems. Wei Wu and R.R.A Issa (2012) propose the practice of matching up particular BIM functionalities and LEED credit requirements represents a primitive stage of BIM/LEED integration. Wei Wu and R.R.A Issa (2010) looked at feasibility of BIM to facilitate LEED certification process and Wei Wu (2010) developed BIM-LEED application model and found it was feasible with considerable constraints. Additionally, Wei Wu and R.R.A Issa(2012) showed the technology core of the could-BIM leveraged LEED Automation framework can be considered well developed and widely adopted in the AEC industry. Tajin Biswas and al. (2013) built 2 prototypes integrating requirements between LEED credit elements and the building in formation modeling elements for pre-evaluation prior to submission for certification.

Overtime, primary technology companies are collaborating with LEED Automation now, such as Autodesk, Integrated Environmental Solutions or IES, Green-grade, TRACE 700 and so on. The products of collaboration are also prevailing in design companies. For instance, Autodesk Green Building Studio (GBS) for daylighting, water consumption and energy simulation; IES automated LEED credit checks. These products are able to purvey sheer improvement for sustainable design. Nonetheless, Wei Wu and R.R.A Issa (2014) recounted barriers to BIM integration in LEED certification as follows: 1. It is not mandatory and motivated for owners to implement BIM and LEED integration. 2. Implementation of BIM and LEED is expensive. 3. Despite current competency of BIM software, many project teams still feel quixotic to use BIM to qualify certain LEED credits. 4. Uneven BIM skills and knowledge reside in team members interrupting interoperability among project teams.

As BIM/LEED integration getting sophisticated, LEED will be incorporated into BIM eventually and project teams will achieve the goal of seamless integration and therefore thoroughly improve efficiency of green building process.

Table 3. Development of synergies between BIM and LEED

	Epitome	Time	description	barrier
phase 1	LEED Online	2006-2010	Strealining LEED certification process	Inferior interoperability; No database support; Lack of previous knowledge usage; Only in Internet Explorer (IE)
phase 2	Synergies between BIM and LEED	2008-2018	Mapping up BIM functionalities and LEED certification process	Information exchange; qualitative credit items; prediction accuracy
phase 3	LEED Automation	2010-2018	Cooperation with third-party technology companies	Expensive; Only dealing with quantitive credit items; Different evaluation criteria
phase 4	BIM/LEED integration	2010-2018	Integrating BIM into LEED certification process	Lack of motivation; Expensive; Not accepted by most of designers; Uneven BIM skills and knowledge
phase 5	Seamless BIM/LEED integration	2018-?	LEED is incorperated into BIM (future speculation)	

4. COMPARISON OF EVALUATION CONTENT BETWEEN LEED ADN G-SEED

Table 2 and Table 3 list related items and unrelated items between LEED and G-SEED based on evaluation content. Related items are divided into 3 categories: basically identical(≌), correlated(=) and partially correlated(≈). There are slight evaluation standard differences existing between basically identical items.

For instance, L-LTc6 and G-LT1.7 are aiming at bicycle facilities. In LEED, different bicycle storages are required depending on commercial or institutional projects, residential projects, mixed-use projects, school, retail and healthcare. For commercial or institutional projects, providing "short-term bicycle storage for at least 2.5% of all peak visitors, but no fewer than four spaces per building and long-term bicycle storage for at least 5% of all regular building occupants, no fewer than four storage spaces." At least one on-site shower for every 100 regular building occupants is required. Moreover, the walking distance between storage and main entry are set within 30 meters. While in G-SEED, the facilities demand are bifurcated to non-residential buildings and schools. The G-SEED only mentions designing 15%-30% of number of parking vehicles for bicycles and on-site shower. Despite the differences existing, this research determines two items as basically identical since they both require bicycle storage and on-site shower. L-EAc5 and G-EP2.5 are concerning with renewable energy production, both have evaluation content in terms of outcome that renewable energy use divided by whole building energy use. The outcome should be 10% to get full credits in LEED, whereas 5% in G-SEED. If the annul energy cost calculated in ASHREA advanced energy design guide was pursued rather than EA Prerequisite Minimum Energy Performance, U.S. Department of Energy's Commercial Buildings Energy Consumption Survey database will be used to estimate energy use and cost. Accordingly, L-EAc5 and G-EP2.5 are determined as basically identical.

Correlated items such as L-LTc5 and G-LT1.6 describe accessibility to public transportation. Minimum walking distances to nearest public transportation station, which is from 200 meters to 400 meters, determines the score in G-LT1.6. L-LTc5 entails "locating functional entry of the project within 400-meter walking distance of existing bus, streetcar or rideshare stops, or within 800-meter walking distance of existing planned bus rapid transit stops, light or heavy rail stations, commuter rail stations, or commuter ferry terminals. Additionally, minimum daily transit service for projects must be met, which is decided by weekday trips (72-360) and weekend trips (40-216) for multiple transit types and 24-40 weekday trips and 6-8 weekend trips for commuter rail or ferry service only. L-LTc5 gives 1-6 credits to it and 2 credits only in G-LT1.6. L-EAc2 and G-EP2.1 are determined as correlated because they account on energy performance. L-EAc2 option 1 marks credits according to percentage improvement from Prerequisite Minimum Energy Performance to building energy simulation. Option 2 follows ASHRAE

Table 4. Related items in LEED and G-SEED

Item code	LEED item	credits	Evaluation content key words	correlation	Item code	G-SEED item	credits	Evaluation content key words
L-LTc2	Sensitive Land Protection	1	Locate on previously developed land	≈	G-LT1.1	Site Ecological Value	2	choose site with low ecological value
L-LTc5	Access to Quality Transit	5	walking didtance to public transportation	=	G-LT1.6	Access to Public Transportation	2	Similar
L-LTc6	Bicycle Facilities	1	Long-term bicycle storage spaces and accessibility	≌	G-LT1.7	Bicycle Parking	2	Similar
L-LTc8	Green Vehicles	1	Installation of electrical vehicle supply equipment(EVSE)	=	G-ID1	Alternative Transportation Management Facility	1	Car-sharing parking, EVSE
L-SSc2	Site Development - Protect or Restore Habitat	2	On-site vegetation restoration	≈	G-E6.3	Ecological Area Rate	6	Planting area
L-SSc4	Rainwater Management	3	Runoff volume, water quality, Low Impact Development(LID)	≈	G-W4.1	Rainwater Management	5	LID, Green Infrustructure(GI), rainwater storage, runoff management
L-WEp2	Indoor Water Use Reduction	Required	Indoor water consumption	≈	G-W4.3	Water Saving Equipment Usage(2)		Water saving equipment and product
L-WEp3	Building-Level Water Metering	Required	Install water meters tracking water consumption	≌	G-W4.5	Water Metering(2)		Equal
L-WEc2	Indoor Water Use Reduction	6	Indoor water consumption, Standards for process	≈	G-W4.3	Water Saving Equipment Usage	3	Water saving equipment and product
L-WEc4	Water Metering	1	Water meters tracking water consumption	≌	G-W4.5	Water Metering	2	Equal
L-EAp1	Fundamental Commissioning and Verification	Required	Commissioning process activities, owner's project requirements(OFR), basis of design(BOD)	≌	G-EP2.2	Testing, Adjusting, Balancing(TAB) and commissing implementation(2)		Equal
L-EAp2	Minimum Energy Performance	Required	Building energy performance	=	G-EP2.1	Energy Performance(2)		Energy Performance Index(EPI), Energy Efficiency Certification
L-EAp3	Building-Level Energy Metering	Required	Install building-level energy meters trachking energy use	≌	G-EP2.3	Energy Monitoring and Management Support Facility(2)		Energy monitoring and data analysis
L-EAp4	Fundamental Refrigerant Management	Required	Do not use chlorofluorocarbon(CFC)-based refrigerants.	=	G-EP2.7	Prohibit Specific Substance for Protection of Ozone(2)		Ozone Depletion Potential(ODP) of refirgerant
L-EAc1	Enhanced Commissioning	6	Implement the commissioning process activities	≌	G-EP2.2	Testing, Adjusting, Balancing(TAB) and commissing implementation	2	Equal
L-EAc2	Optimize Energy Performance	18	Building energy performance	=	G-EP2.1	Energy Performance	12	Energy Performance Index(EPI), Energy Efficiency Certification
L-EAc3	Advanced Energy Metering	1	Install advanced energy metering	≌	G-EP2.3	Energy Monitoring and Management Support Facility	2	Energy monitoring and data analysis
L-EAc5	Renewable Energy Production	3	Renewable energy production	≌	G-EP2.5	Renewable Energy Use	3	Equal
L-EAc6	Enhanced Refrigerant Management	1	Calculation of refrigerant impact	=	G-EP2.7	Prohibit Specific Substance for Protection of Ozone	3	Ozone Depletion Potential(ODP) of refirgerant
L-EAc7	Green Power and Carbon Offsets	2	Energy addressed by green power or carbon offsets	≈	G-EP2.6	Low-carbon Energy Resource Technology	1	Heating, cooling energy resourcce
L-MRp1	Storage and Collection of Recyclables	Required	Area for collection and storage of recyclable materials	≌	G-MR3.6	Storage and Collection of Recyclables	1	Equal
L-MRp2	Construction and Demolition Waste Management Planning	Required	construction and demolition waster management plan	≈	G-ID5	Green Construction Site environmental Management Execution (2)	1	Construction Site environmental Management
L-MRc1	Building Life-Cycle Impact Reduction	5	Building and material reuse; life-cycle assessment(LCA)	≌	G-ID3	LCA and Building structure reuse	2+5	Equal
L-MRc2	Building Product Disclosure and Optimization - Environmental Product Declarations	2	Environmental Product Declaration(EPD) materials; low impact products	≌	G-MR3.1	EPD Product Usage	4	Equal
L-MRc3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	Raw material source and extraction criteria	≈	G-MR3.3	Recycling Material	2	Material from recycling resource
L-MRc4	Building Product Disclosure and Optimization - Material Ingredients	2	Material ingredient reporting and optimization	≈	G-MR3.4	Harmful Substance reduced material	2	Harmful substance reduced material certification
L-MRc5	Construction and Demolition Waste Management	2	Divert total construction and demolition material; reduction of total waste material	≈	G-ID5	Green Construction Site environmental Management Execution	1	Construction Site environmental Management
L-EQp1	Minimum Indoor Air Quality Performance	Required	Minimum outdoor air intake flow for mechanical ventilation systems	≈	G-EQ7.2	Natural Ventilation	2	Operable window area, floor area
L-EQc2	Low-Emitting Materials	3	Thresholds of compliance with emissions and content standards of materials	≈	G-EQ7.1	Interior Air Pollutant Low-emitting Material Usage	3	low-emitting interior material
L-EQc5	Thermal Comfort	1	Heating, ventilating, and air-conditioning(HVAC) systems, building envelope standard, thermal comfort control	≈	G-EQ7.5	Thermoregulator Installation	2	Thermoregulator installation
L-EQc6	Interior Lighting	2	Lighting control, lighting quality	≈	G-EP2.4	Illumination Energy Saving	4	Occupied space lighting density
L-EQc9	Acoustic Performance	1	HVAC background noise, sound transmission	=	G-EQ7.8	Traffic noise, exterior and interior noise	2	Sound isolation performance
L-INc1	Innovation	5	Innovation design	≌	G-ID9	Innovation Design	3	Equal
L-INc2	LEED Accredited Professional	1	LEED experts participation	≌	G-ID8	Green Building professional	1	Equal

Note

≌ This denotes two items are basically identical. They have equal requirements or evaluation content, nontheless, there may have slight difference in standards.

=This denotes two items are correlated. They have common purpose or similar evaluation content.

≈This denotes two items only partially correlated.

Code explanation: L- LEED, G- G-SEED.

Category acronym in LEED: location and transportation (LT), sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (EQ), innovation (IN). In G-SEED: Land use and Transportation (LT); Energy and Pollution (EP); Materials and Resources (MR); Water (W); Management (M); Ecology (E); Indoor Environment Quality (EQ); Innovative Design (ID)

c- credit; p-prerequisite: Number- sequence

Table 5. LEED items can be earned by BIM

LEED item	credits	correlation with BIM	software	LEED evaluation standards key words	How can BIM earn the credit
L-SSc3	1	indirect	Revit	outdoor space greater than or equal to 30% of total area, vegetating 25% of outdoor space, physically accessible	Building mass and site
L-SSc5	2	indirect	Revit	Area of high-reflectance roof, area of vegetated roof, Total site paving area, total roof area	Building properties, massing
L-SSc6	1	indirect	Revit	uplight and light trespass, backlight-uplight-glare; calculation method	Building properties, Material Documentation
L-WEp1	R	direct	GBS	Reduce landscape water requirement by at least 30% from the calculated baseline; No irrigation required	Water usage and outdoor water factors
L-WEp2	R	direct	GBS	Reduce aggregate water consumption by 20% from baseline	Water usage and cost in GBS
L-WEc1	2	direct	GBS	Further reduce Landscape water requirement(LWR) by at least 50%-100% from calculated baseline	Water usage and outdoor water factors
L-WEc2	6	direct	GBS	Futher reduce fixture and fitting water by at least 25%- 50% from baseline	Water usage and cost in GBS
L-EAp2	R	indirect	GBS	Whole-BuildingEnergy Simulation; improvement 5% for NC	Energy simulation in GBS
L-EAc2	18	indirect	GBS	Energy simulation; performance improvement at least 6%-50% compared with baseline building performance rating	Energy simulation in GBS
L-EAc5	3	semi-direct	GBS	renewble energy cost; Total building annual energy cost; 1%, 3%, 5%, 10%	GBS provides annual energy cost simulation and photovoltaic and wind energy potential calculation(without geothermal heat pump)
L-MRp1	R	indirect	Revit	Easily-accessible, dedicated area, recycling, minimum, paper, corrugated cardboard, glass, plastics and metals	Material Documentation
L-MRc1	5	indirect	Revit	Percentage of completed project surface area reused, 25%, 50%, 75%; Life cycle assessment(LCA), minimum 10% reduction compared with baseline, at least three impact categories for reduction	Material Documentation
L-MRc2	2	indirect	Revit	Use at least 20 different permanently installed Environmental Product Declaration(EPD)products; product below 50% cost, global warming potential; stratospheric ozone layer, etc	Material Documentation
L-MRc3	2	indirect	Revit	raw material suppliers extraction locations; Ecologically responsible land use, reducing environmental harms, meeting applicable standards.	Material Documentation
L-MRc4	2	indirect	Revit	20 different products, chemical inventory of the product to at least 0.1%(1000ppm); ingredient optimization; manufacturer supply chain optimization	Material Documentation
L-EQc7	3	direct	GBS	annual computer simulation, daylight autonomy of55%, 75%regularly occupied floor area; illuminance levels between 300lux and 3000lux for 9 a.m and 3 p.m	Annual daylight analysis in GBS

Table 6. G-SEED items can be earned by BIM

G-SEED item	credits	correlation with BIM	software	G-SEED Category key words	How can BIM earn the score
G-LT1.2	3	indirect	Revit	Basement floor area; floor area, story height; 200%-500%	Building Mass
G-LT1.4	2	indirect	Revit	building height, property line, 40-55 degree	Building Mass
G-EP2.1	12	indirect	Green Building Studio (GBS)	EPI, Building Energy Efficiency Certification, Required primary energy per unit area per year	Required primary energy per unit area per year can be simulated by GBS and thereby calculating energy efficiency scores
G-EP2.4	4	semi-derect	Elumtools for Revit	Main used space, ceiling lighting density	Illuminance simulation and calculation
G-EP2.5	3	semi-derect	GBS	annual usable energy produced by renewable energy system/ total building annual energy consumption, at least 2%,3%,4%,5%	GBS provides annual energy cost simulation and photovoltaic and wind energy potential calculation(without geothermal heat pump)
G-MR3.1	4	indirect	Revit	1-4 classes building material, 3-6 Environmental Product Declaration(EPD) products.	Material documentation
G-MR3.2	2	indirect	Revit	number of low-carbon materials, more than 1-7	Material documentation
G-MR3.3	2	indirect	Revit	number of recycling materials, more than 5-20	Material documentation
G-MR3.4	2	indirect	Revit	number of Harmful substance reduced materials, more than 5- 20	Material documentation
G-MR3.5	4	indirect	Revit	investment on Green building materials; construction expenses; ration above 1%-7%	Material documentation
G-EQ7.1	3	indirect	Revit	low-emitting interior materials, binding materials and finishing materials	Material documentation
G-EQ7.2	2	indirect	Revit	Operable window area,floor area,2%-8%	Building Massing
G-ID3.2	5	indirect	Revit	Remodeling, structure reuse, more than 30%-60%	Material documentation
G-ID4	1	indirect	GBS	Grain water usage, Building water use, ratio above 4%-10%	Water usage and cost in GBS

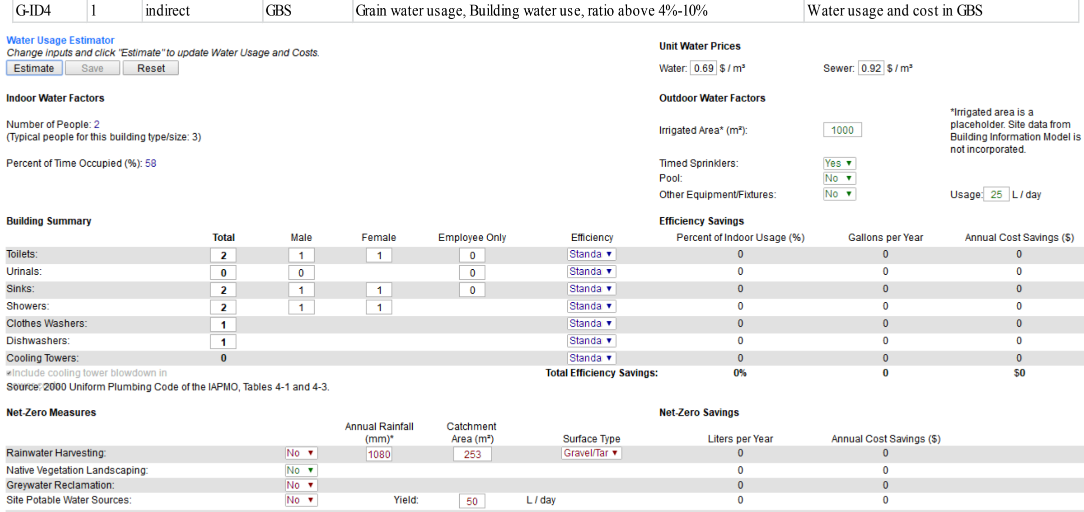


Figure 1. Renewable energy potential estimation in GBS

avanced Energy Design Guide with maximum 6 credits. G-EP2.1 has 3 criteria: Energy Performance Index (EPI); building energy efficiency rate; Energy-saving building 30% - 55% energy saving.

L-SSc4 and G-W4.1 are partially correlated. They both contain requirement for managing on site the runoff from the developed site using Low Impact Development (LID) and green infrastructure (GI). L-LTc5 has other option for Natural Land Cover Conditions. G-W4.1 attaches importance to that LID and GI should be set on the basis of volume that rainwater management multiply 0.005-0.03 meters.

The rest of items such as G-LT1.2 underground space development, which is about restricting Underground Facilities-to-Land Ratio, does not have corresponding items in LEED. They are listed as unrelated items.

There are some annotations to the comparison table. 1. Some credit items in LEED are enhanced extension of corresponded prerequisite item. The table uses (2) to evince repetition of same items. 2. According to LEED, projects attempting L-LTc1 for Neighborhood Development Location are not eligible to earn other points, therefore this item LTc1 is omitted from this table. 3. G-SEED items which are aiming at only one or two types of building are omitted from this table. 4. The table also omits Regional Priority in LEED.

As a result, 13 groups of items are basically identical; 7 groups of items are correlated; 14 groups of items are partially correlated. Additionally, 27 G-SEED items (64% of all) can be related to 34 LEED items (65% of all) on different degrees. Meanwhile 77 credits (70%) in LEED can be related to 74 credits (70%) in G-SEED.

The functionalities of BIM software will be matched up with LEED and G-SEED certification requirements. Table 4 and table 5 illustrate investigation about which items' credits in LEED and G-SEED can be earned and how to be earned by BIM. The BIM and LEED integration products can be used to earn credits directly. For instance, daylight analysis in GBS provides LEED daylight credits, as shown in figure. When only some supporting documents for the credit can be generated using the software, credits can be earned semi-directly. The indirect credits indicate that BIM can only proffer key information for LEED credit items.

Energy, Carbon and Cost can be summarized in Energy and Carbon Results of GBS, which fulfills part of requirement of the item that annual energy usage meets the Building Energy Efficiency Certification criteria or option 1 of L-EAc2. Photovoltaic, Wind Energy and Natural Ventilation Potential in GBS can partially be contributory to G-EP2.5 and L-EAc5, basically identical items refer to annual renewable energy cost. Wind energy annual electric generation can be calculated in GBS. In photovoltaic potential calculation, panel type, panel efficiency, installationcost, area of roof (which is provided by roof schedule in Revit including direction, tilt degrees, panel area, solar exposure and obstruction shading) are considered to calculate Annual Energy Production and Payback Period.

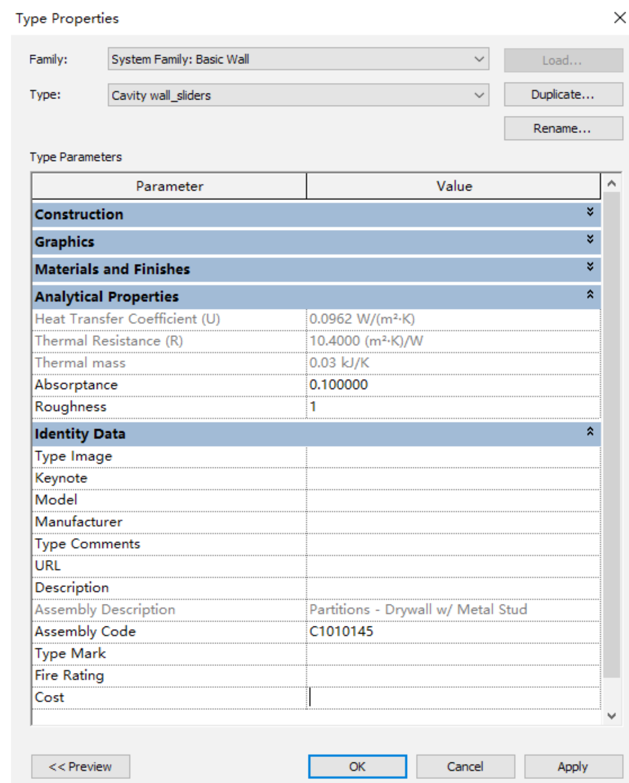


Figure 2. Type properties in Revit

Moreover, Type Properties advert to properties of structural components in Revit. A project component can be invest with Analytical Properties (physical properties such as thermal coefficient), identity data, which involves manufacturer, assembly code, cost and so forth, and other features. For instance, L-MRc2 option 1 posits use as least 20 different permanently installed Environmental Product Declaration (EPD) products. The information concerning with EPD can be documented in type properties, and eventually, the ensemble of material will be able to be displayed in material schedule, which can conveniently find corresponded material documentation. Besides, GBS daylight analysis and water efficiency can be used to appraise LEED credits directly.

Consequently, it was found that 12 credit items and 4 prerequisite items in LEED worth a total of 47 credits may be directly, semi-directly or indirectly earned by BIM software. Along with 14 G-SEED items worth totally 51 credits may be directly, semi-directly or indirectly earned by BIM software.

Furthermore, in LEED, 3 item for 11 credits and 2 prerequisite items may be earned directly by BIM software; 1 item for 3 credits may be earned semi-directly; 8 items for 33 credits and 2 prerequisite items may be earned indirectly. In G-SEED, no items can be earned directly; 2 items for 7credits may be earned semi-directly; 12 items for 42 credits may be earned indirectly by BIM software.

The evaluation requires complex submittal work. The nature predetermines that GBA work could only be partially supported by BIM software. More credits can be earned directly in LEED than credits in G-SEED, because of sophisticated development of BIM/LEED integration.

5. CONCLUSION

The following conclusions can be drawn from this study: Synergies and integration of BIM and LEED have been researching for several years. Companies sought to take advantage of integration and interoperability of BIM to facilitate sustainable design and thereby alleviating buildings' impact on global environment. The development can be divided into five phases. Since LEED automation has launched, many technology companies have been working with LEED automation and have collectively exploited products, which can significantly facilitate application process of LEED certification by saving time and relieving administrative burden. Although BIM/LEED integration is getting more sophisticated, it still has barriers to overcome. In future, integration of BIM and LEED will play a major role on AEC industry.

Comparison of items' evaluation content between G-SEED and LEED evince G-SEED bears a strong resemblance to LEED. 65% of LEED and 64% of G-SEED share common evaluation content in different degrees. Therefore, it is entirely possible for G-SEED to adapt LEED automation developing mode: cooperating with technology companies to develop program, accelerating certification progress and then integrating G-SEED and building information modeling.

47 credits and 51 credits can be earned directly, semi-directly or indirectly by BIM in LEED and G-SEED respectively. Both credits can reach minimum certification in G-SEED green level 4 and LEED certified. Due to exploited integrating products of BIM and LEED, more credits can be earned directly or semi-directly in LEED. Yet G-SEED has huge potential for developing integrating products with technology companies.

It is possible that BIM software not mentioned in this study can earn more other credits in LEED or G-SEED. In future research, investigation should be proceeded with broader range of knowledge about BIM system. It is important to ascertain about financial benefits and practical maneuverability of results from this study for design companies, since this study focus on theoretical investigation. Case study is also needed to corroborate the reliability of this study.

Table 7. Summary of related items and credits can be earned by BIM

	LEED	G-SEED
Number of related items	34	34
Proportion of related items in number of total items	65%	64%
Related items' credits	77	74
Proportion of related items' points in total credits	70%	70%
How many items can be earned by BIM	16	14
How many credits can be earned by BIM	47	51
Proportion of credits can be earned by BIM in total credits	43%	48%

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