GREEN BIM

— Sustainable Design with Building Information Modeling

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Contents

Abstract

Environmental concerns such as global warming are increasing the demand for green buildings. Green building design needs to comprehensively consider factors such as geography, climate, materials, and cost, and is a highly complex multidisciplinary research problem. Therefore, there is an urgent need to adopt advanced modeling and simulation technologies, including BIM, parametric design, cloud platform, and performance simulation.

The most important decisions about a building's sustainable character are made during the design and pre-construction phases. Leadership in Energy and Environmental Design (LEED®) is the most widely adopted sustainable building rating system in the United States. For projects seeking LEED® certification, designers must conduct an in-depth sustainability analysis based on the building's form, materials, environment, and mechanical electrical plumbing (MEP) systems. As a building model that contains a large amount of data information, the use of BIM technology forms an information flow throughout the entire design phase of the project in the architectural design process, and can exchange data with various green building performance analysis software through common format files, which enables us to use the BIM model to realize the design process of designing, simulating and optimizing at the same time.

The research content is how to combine the advantages of BIM technology with green building information statistics, performance analysis and green building evaluation system in the design stage of construction projects, so as to conduct green building performance simulation and scheme optimization more conveniently and accurately. In this exploratory study, a case study of a student residence in Milan is demonstrated for the use of BIM in the sustainable design and LEED® certification process. First, a 3D information model of a project is established. Next, a conceptual framework was developed to establish the relationship between BIM-based sustainability analysis and the LEED® certification process. Finally, the framework is validated through this case study, illustrating how to achieve green building information statistics, performance analysis, and green building design optimization and evaluation in the architectural design stage based on BIM technology, and discusses the application, advantages and limitations of the framework.

The results of this study demonstrate that documentation supporting LEED® credits can be prepared directly or indirectly using the results of BIM-based sustainability statistics and analysis software. This process simplifies the LEED® certification process and saves significant time and resources. This study has contributed to the field of multidisciplinary sustainability research, and is an important supplementary optimization design for green building evaluation.

Keywords: Building information modeling; Green building evaluation; LEED® rating system; Performance optimization; Sustainability

1. Introduction

1.1 Introduction to Building Information Modelling

As a multi-function method, Building Information Modeling (BIM) makes a significant contribution to the Architectural Engineering and Construction (AEC) industry. According to the British Standards Institution, BIM uses shared digital representations of building assets to promote the design, construction, and operational process and form a reliable basis for decision making.

Construction projects generally go through several stages of planning, design, construction, operation and maintenance, and a large number of partners participate in these stages, which involves the transmission and exchange of information. In each stage, the problems of "information gap" and "information island" between partners are common. BIM technology can not only present the design results in 3D and associate the design drawings, but also realize the sharing, integration and management of engineering information in the whole process, and improve the management level. In addition, it lays the groundwork for later implementation by setting solid engineering goals up front.

For the process, the first step of BIM workflow is to establish a 3D information model of the building, and on this basis, include all parts of the building's life cycle into the 3D information model, including the feasibility analysis, design, construction, operation, maintenance and other phases of the project. Participants in each phase can use the 3D information model to carry out work related to this phase. In addition, BIM is not a design methodology or an aggregate set of design methodologies but a powerful tool for synergistic integration of skills. Thus, designers also when operating in BIM must have all the necessary skills.

1.2 Introduction to Green building

Green building design has experienced decades of development from concept generation to current development. Although there is no uniform definition of green building in the world, the principles and goals of green building design in various countries are still close to the same, which can be summarized as follows:

1. Green building is a building that pursues resource conservation and maximum environmental protection throughout its life cycle.
2. Green building design needs to adapt to local conditions, select technologies, equipment and materials suitable for local climate and resource conditions, and comprehensively consider factors such as safety, economy, durability and aesthetics.
3. Green buildings need to comprehensively evaluate the relationship between building site, climatic conditions, building scale, building form and investment.
4. Green buildings should adopt more passive technologies and optimize them with active technologies. They should focus on design, supplemented by technology, and make best use of the climate and site resources of the site.

Table 1 shows the definitions of green buildings in various countries.

Table 1
Definitions of green buildings in various countries.

Nation	Institution	Definition on Green Building
US	US Environmental Protection Agency	Green building refers to a structure and process that is responsible for the environment and uses resources efficiently in the whole life cycle of the building.
UK	Building Research Establishment	Green building helps preserve nature and is a more sustainable type of building.
Europe	European Commission	Green building helps protect the environment and improve occupant space and air utility.
Singapore	Inter-Ministerial Committee on Sustainable Development	Green buildings are composed of environmentally friendly building materials, which can save energy and water, and ensure a healthy and high-quality internal environment.

2 Managing Sustainability with Green BIM

2.1 A Definition of Green BIM

As the connection of sustainable design (Green) and Building Information Modelling (BIM), a variety of definitions of Green BIM exists in the literature. The simplest definition is probably the one proposed by (Smart Market Report 2010): “The use of BIM tools to help achieve sustainability and/or improving building performance objectives on a project”.

In 2008, Eddy Krygiel and Bradley Nies first introduced the concept of Green BIM, which they defined as "the process to generate and manage the full-lifecycle data information of building based on the building information model, improving the building performance, promoting and achieving the expected sustainable goal". Also based on an analysis of related literature, Gandhi and Jupp (2013) highlighted the functionality of green BIM as a tool to support the use of environmental certification protocols for buildings, infrastructures or neighbourhood such as LEED or BREEAM, in which they identified three fundamental pillars of Green BIM (Figure 1)：

1. Environmentally sustainable design (ESD) principles;
2. Optimisation of the process of obtaining prerequisites and credits in order to obtain green building certification (GBC);
3. Integrated building systems and design processes supported by object-based modelling and analysis tools supported by BIM platform.

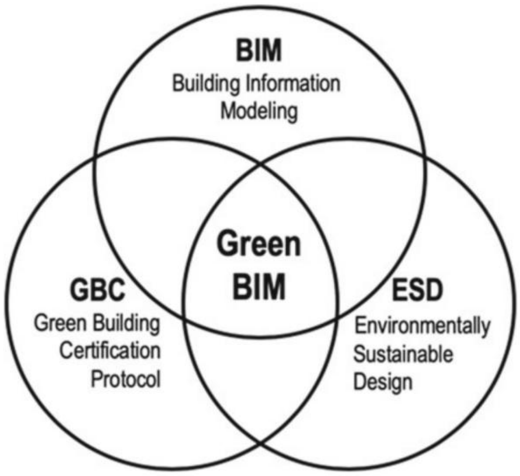


Figure 1. Three fundamental pillars of Green BIM

The Green BIM decision process is designed to evaluate different design criteria and goals. It requires the following steps: first, to fully understand the local climate and environment of the site; second, to reduce energy demand and improve energy performance; third, to set evaluation benchmarks and project goals; finally, to choose the appropriate BIM software and establish models step by step for targeted visual analysis.

Various BIM software programs provide data exchange functions. The data in the model is input into relevant analysis software through IFC, gbXML and other exchange formats, and the calculation and analysis results are presented in a short time. Through such a decision process, the original scheme can be optimized and modified to provide guarantee for the rapid decision-making of green building designs.

2.2 The Necessity of Combining Green Building and BIM

2.2.1 Needs of Industry Development

At present, BIM technology and green building are an important development direction in the construction field. "Green BIM" refers to the use of BIM technology to improve the performance of buildings and realize the sustainable development of buildings. It is the fusion of two technologies. It can be understood that green building is an important goal of "carbon neutrality" in the construction industry, and BIM technology is a technical auxiliary means to achieve "carbon neutrality", helping design and optimization. Therefore, BIM technology is an important guarantee for the sustainable and green development of the construction industry.

2.2.2 Compatibility in the Time Dimension

From the concept of green building and the core of BIM technology, we can see that the focus of green building is on energy saving, emission reduction and sustainable development in the whole process from the planning, design, construction and operation of the building; and BIM technology can also carry out one-to-one correspondence to the above-mentioned processes, from planning and design to operation and maintenance, to the final demolition, BIM technology can analyze the whole process. Therefore, it can be considered that BIM technology and green buildings have a relatively close match in the time dimension.

2.2.3 Complementary of Information Demand and Supply

In the process of green building performance simulation, it is necessary to use the building information model as the data basis to support the simulation analysis. This process requires high accuracy and completeness of the building information model, and the core advantage of BIM technology is to realize the accurate construction of the building information model, so that the information model contains the detailed information of the building, including the basic geometric information of the building such as length, width and height, etc.; the basic physical properties of the building, including the structure of the building, the thermal parameters of materials, the amount of construction work and the cost of the building, etc.; and the topological relationship inside the building, such as the upper and lower relationship of the building, the internal and external relationship, etc.

Scholars have conducted in-depth research on the standardization of BIM component libraries. Li et al. (2020) calculated the attribute similarity in building components to realize the retrieval of building components in the BIMSeek resource library as Figure 2 shows. Fleming et al. (2017) present the US Department of Energy's Building Component Library (BCL), an online repository of building components that can be directly used to create energy models. In order to achieve the consistency of BIM product library, Lucky et al.(2019) propose an interoperable method for sharing product data to facilitate the management, query and sharing of product data.

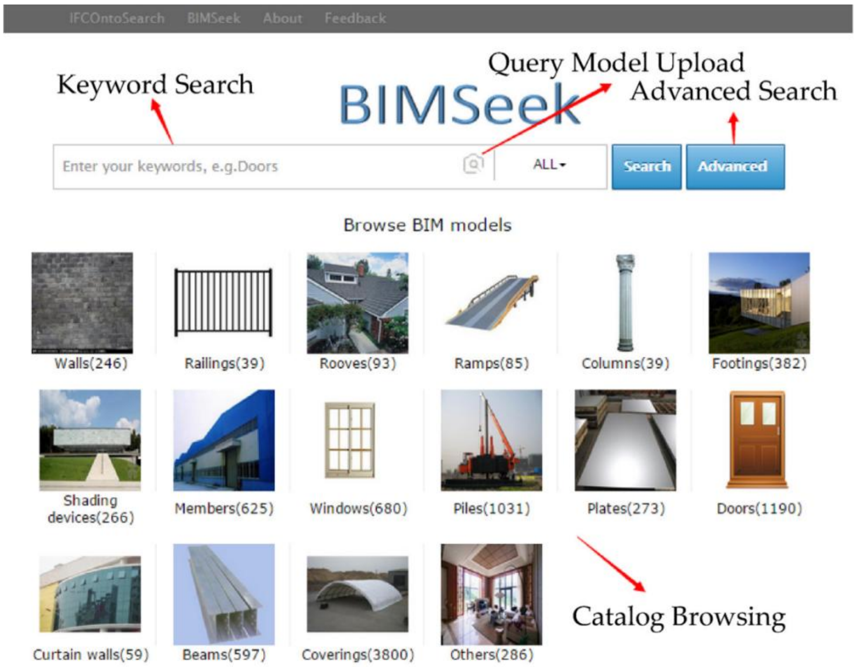


Figure 2. Features of the upgraded BIMSeek system by LI et al.

2.2.4 Collaboration of Multiple Disciplines

Green building is a comprehensive design result across multiple disciplines. In the design process of green building, the support of BIM technology can meet the design requirements of each stage in the architectural design process. During the process, structural design, HVAC design, water supply and drainage design, etc. can be integrated into the joint participation, and the green building design can be realized through collaboration. At the same time, through the collaborative design of BIM, it is also possible to avoid design modifications caused by content duplication and conflicts in the design process, saving the design process and improving design efficiency. The good coordination performance of BIM can quickly integrate building information, realize information management, and promote the transformation and upgrading of the construction industry.

To exploit this capability, researchers seek to better understand stakeholder collaboration processes. Oraee et al. (2019) propose a conceptual model to capture the main collaborative barriers in a BIM-based building network, divide the collaborative barriers into five categories of context, process, team, task, and participant, and analyze the barriers of each category as Figure 3 shows. Papadonikolaki et al. (2019) analyze two BIM-based construction projects in the Netherlands from the perspective of boundary theory, and discuss the organizational collaboration structure in the implementation of BIM. Matthews et al. (2018) conduct an exploratory case study examining BIM practice from a collaboration and management perspective, noting that project teams had limited experience and knowledge in delivering asset management models and that the lack of BIM knowledge impacts work practices.

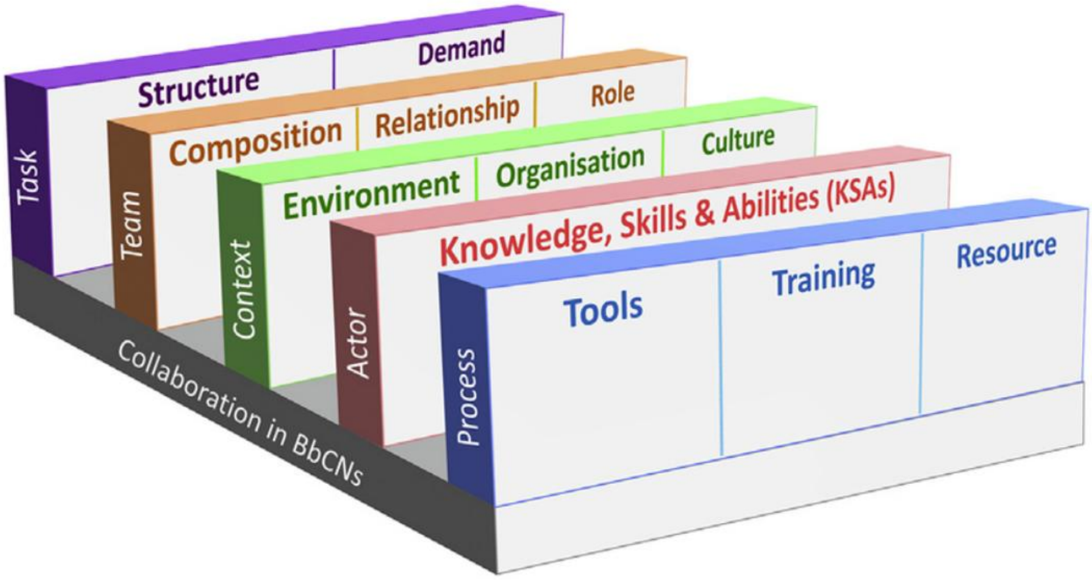


Figure 3. Conceptual model for collaboration by Oraee et al.

2.2.5 Defects of Traditional Green Building Design

The performance analysis of traditional green buildings is usually carried out by professional performance analysts, who use special performance analysis tools to comprehensively analyze the sound, light, heat and wind environment of the building. When analyzing the above content, different analysis software is usually used to carry out manual modeling and then analyze and calculate. In this process, once the model is modified, it needs to be re-modeled and calculated in professional analysis software. In this way, the modeling work is repeated and human resources are wasted. The building information model based on BIM technology can be integrated with various building performance analysis software to realize building performance analysis and calculation, so as to reduce the workload of repeated modeling and parameter setting, and improve work efficiency.

In this field, many scholars have studied the interoperability between BIM software and BPS(Building Performance Simulation) software. Calquin et al.(2014) sort out the format conversion workflow between BPS software and BIM software. Negendahl et al.(2017) summarize the current application of BPS technology in engineering projects. He believes that the combination of design tools, visual programming softwares and BPS softwares is more conducive to the feedback of BPS in the early design stage than the traditional use of IFC or gbXML format files. Changmin Kim et al.(2019) develope a method for automatic conversion of BIM windows into models in thermal simulations as Figure 4 shows. Ando et al.(2018) develope a technical method to automatically project IFC files from BIM into Modelica models (Figure 5).

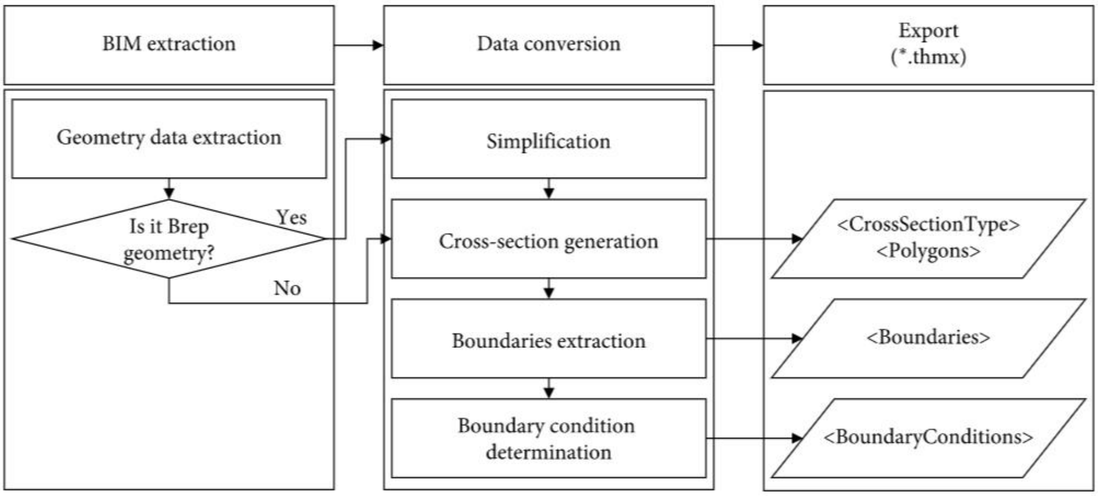


Figure 4. BIM-based framework for window thermal performance simulation by Kim et al.

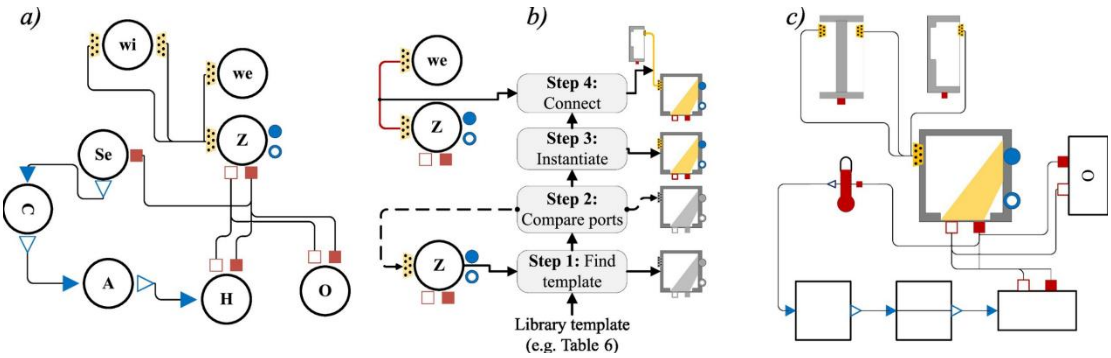


Figure 5. Overview of the mapping process by Ando et al.

In summary, it can be seen that for green buildings, using BIM technology to model them and calculate on professional tools can effectively analyze the overall performance of the building. It can be taken as the data support of building optimization analysis, so as to complete the optimal design of green buildings, meet the requirements of green building evaluation standards.

2.3 Leadership in Energy and Environmental Design (LEED®)

The growth of Green BIM reinforced the correlation between the growth of the green and sustainable certified building and the use of BIM tools. The most widespread experiences in this regard concern in particular are the Green BIM and the LEED® protocols.

The LEED® evaluation system was proposed by the U.S. Green Building Council. There are four levels of LEED® certification which are LEED® Certified, LEED®

Silver, LEED® Gold and LEED® Platinum. The level of LEED® certification a building can achieve is determined by the number of points awarded as Table 2 shows. It is a relatively complete green building evaluation system with the fastest version update (every three years on average) and the highest marketization and commercialization in the world. The LEED® evaluation system has great influence, and its scientific and operability and other characteristics directly or indirectly affect the research and formulation of green building evaluation systems in other countries. It has covered all building types and every aspect of the building's life cycle. The perfect system has corresponding evaluation methods for design, construction, operation and demolition phases. The evaluation factors include building energy consumption, emission reduction capabilities and environmental protection, etc. In addition, the system also considers indoor environmental factors such as indoor air quality and indoor pollutants. The relatively comprehensive evaluation factors help evaluators comprehensively evaluate green buildings from multiple perspectives such as building site selection, material properties, material utilization, and indoor environment.

Table 2

Levels of LEED® Certification.

Level	Point requirements
Leed® Certified	40-49 points
Leed® Silver	50-59 points
Leed® Gold	60-79 points
Leed® Platinum	≧80 points

3 Literature Review

As people pay more attention to the protection of environment, under the guidance of the concept of sustainable development and green construction, researchers have carried out many studies on the integration of BIM and green buildings.

3.1 Green BIM in the Planning and Design Stage

In terms of feasibility study, construction scheme, and schedule formulation, the consequences and impacts of different green building construction schemes can be simulated through the simulation function of BIM. Green BIM in the planning and design stage involves building site selection, sunshine, climate and humidity analysis, selection and analysis of building materials, analysis of building indoor and outdoor environment, building performance analysis and simulation, etc. BIM and related tools have many advantages that are conducive to the development of green buildings, such as integration with different databases, visualization of analysis results, and various energy consumption simulations.

Because of these advantages, a lot of research has been done on the application of BIM in green building designs. Lee et al.(2018) use BIM-based green building design methods, combined with green building analysis software to simulate and analyze the optimal design of solar radiation, natural lighting, natural ventilation and noise. Gao et al. (2019) propose a BIM-based building energy model(BEM) evaluation method (Figure 6). Z. Pezeshki et al.(2019) believe that the development of BIM information database is the basis of BEM model, and the lack of interoperability between BIM and BEM models will lead to difficulties in the development and delivery of sustainable and efficient energy projects throughout the life cycle of building projects (Figure 7). Sanhudo et al. (2018) testified the technological capability of BIM for energy retrofitting. Stegnar et al.(2019) presented a hybrid method based on BIM and other information technologies to support energy rehabilitation processes ranging from energy usage diagnosis to retrofitting decision-making. Mark Kyeredey et al.(2021) find that building energy model, indoor and outdoor environmental quality, carbon emission analysis and assessment are the focus of the application of BIM in green buildings.

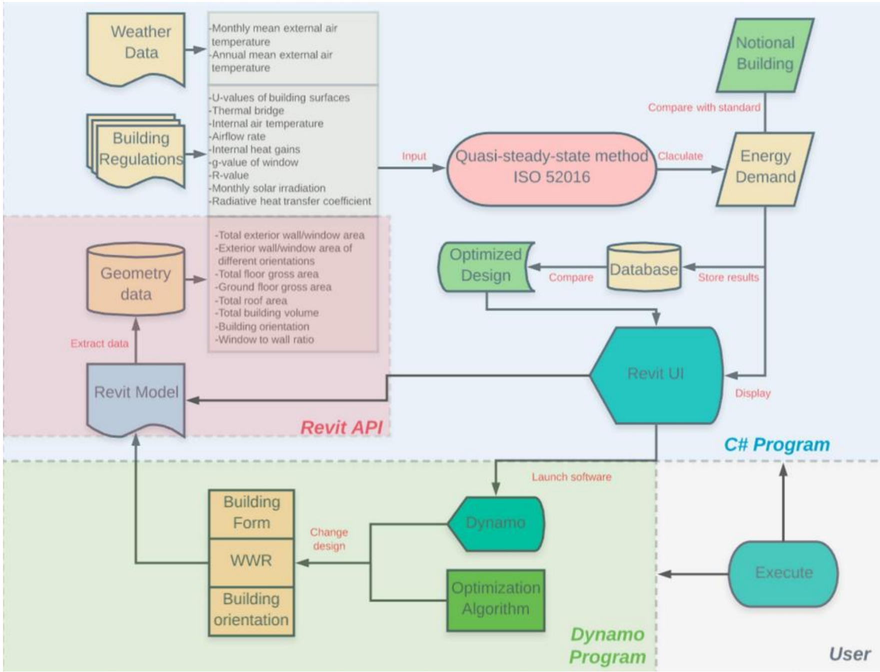


Figure 6. The framework of BIM-based real-time BEM system by Gao et al.

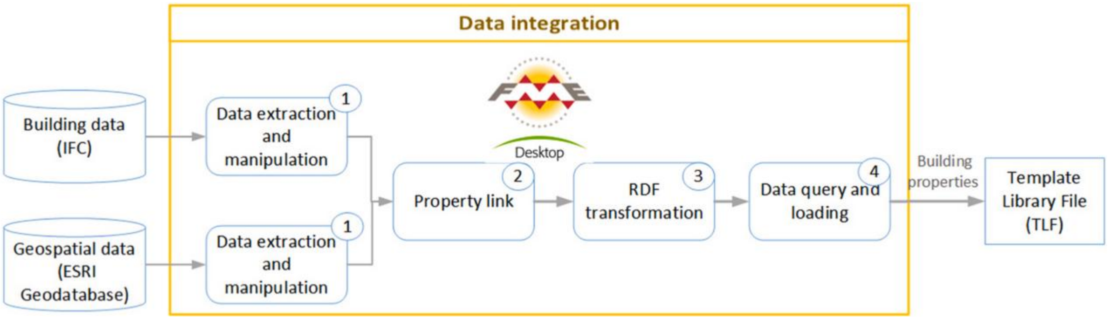


Figure 7. Overview of the data integration process by Z.Pezeshki et al.

3.2 Green BIM in the Construction Stage

Green BIM in the construction stage mainly involves the control of carbon emissions, noise pollution, resource consumption, waste gas and water during the construction process. For example, by extracting the relevant data of the BIM model to measure the carbon dioxide emissions during the construction process, we can propose methods to reduce related carbon emissions. One of the most important analytical indicators among them is Life Cycle Analysis, LCA is a tool for studying the environmental aspects of construction processes or buildings, taking into account the entire life cycle from cradle to grave(ISO 14040， 2009). In this consideration, the natural environment, human health and resource degradation are taken into account to avoid complications between different life cycle stages, between regions and between environmental challenges. Teng et al.(2022) believe Digitalization in the construction industry is considered as a potential way to improve the environmental performance of buildings throughout their life cycle. Building Life Cycle Assessment integrated into Building Information Modeling facilitates data capture and reduces labor-intensive processes.

Antón et al.(2014) emphasize the importance of integrating LCA into a BIM environment. Kreiner et al.(2015) developed an LCA-based approach to the environmental assessment of buildings, which acknowledged the integration of LCA into BIM as a way to improve the sustainability performance of buildings. Carvalho et al.(2020) emphasize the relationship between LCA and the environmental assessment of buildings in BIM in the Portuguese context by conducting LCA with a case study (Figure 8). Cheng et al. (2020) proposed an environmental assessment method for large public buildings using BIM and LCA to better understand the environmental impact of buildings (Figure 9). However, according to Carvalho et al., the integration of BIM and LCA in built environmental assessment methods has not been fully explored.

Through a case study of an institutional building in Egypt, Alothman et al. (2021) demonstrate the effective contribution of building information modeling (BIM) to support sustainable decision-making in buildings. Benefiting from the BIM-based life cycle data management approach, the Shanghai Center achieved a material waste rate of 4%, far below the average level in China.

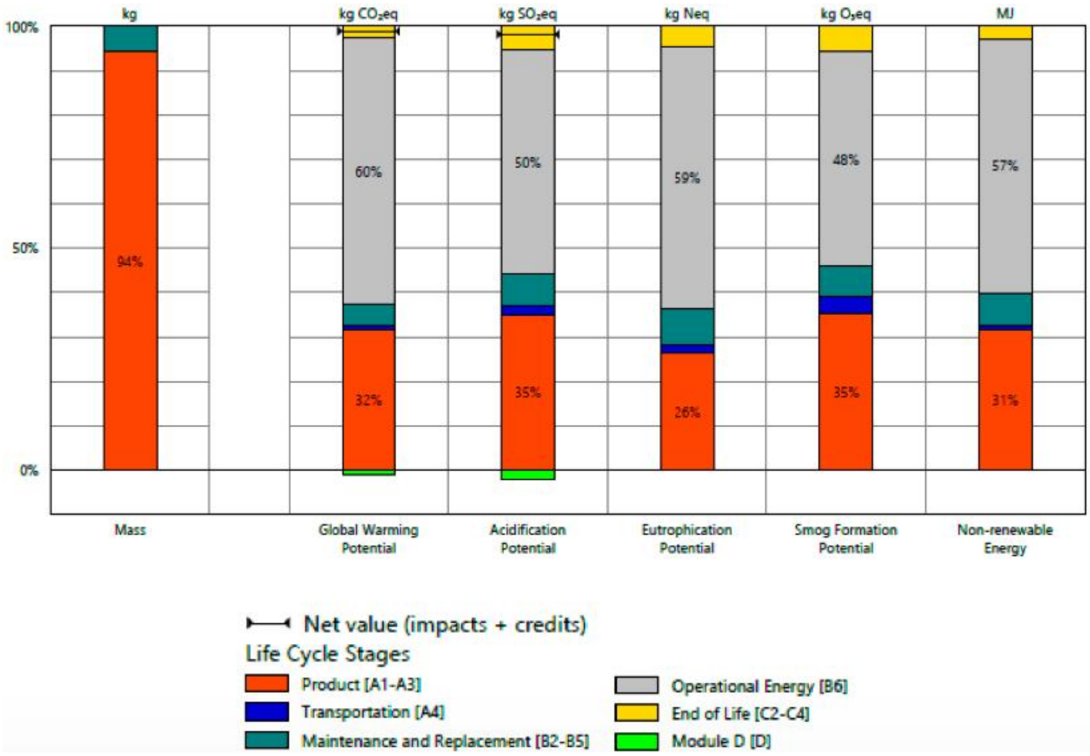


Figure 8. Environmental impacts per life cycle stage by Carvalho et al.

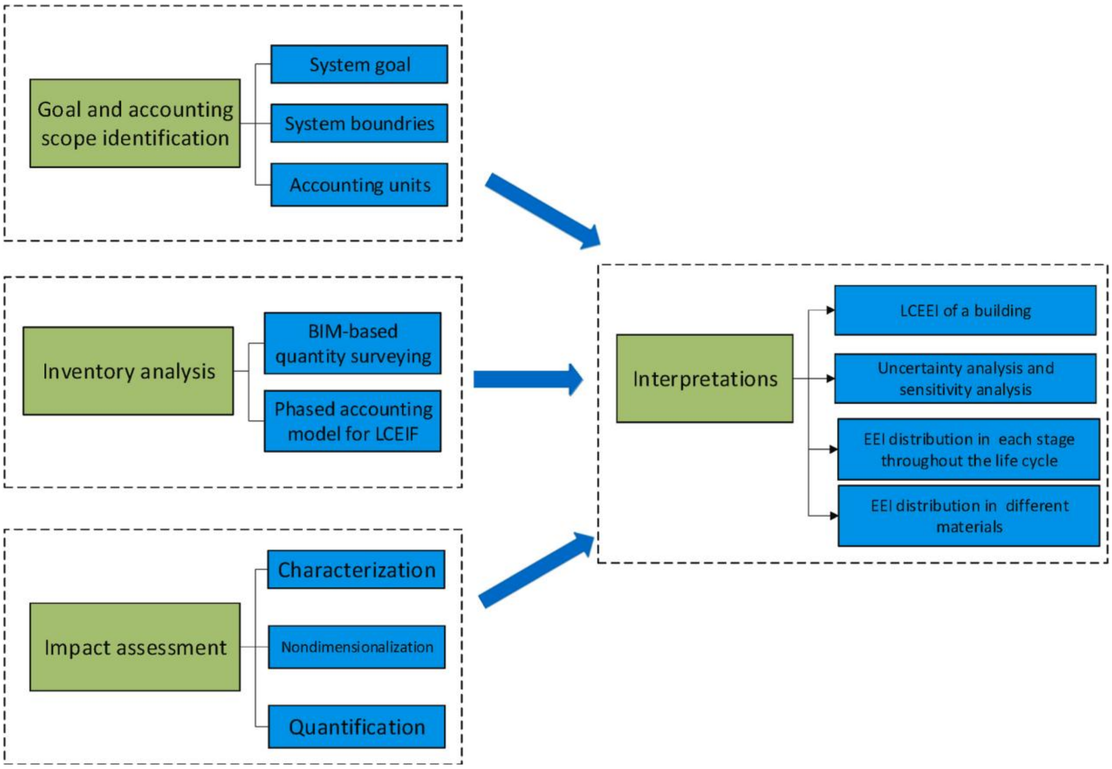


Figure 9. Framework for LCEEI assessment based on LCA-BIM by Cheng et al.

3.3 Green BIM in the Operation and Management Stage

The operation and management stage is an important stage for the sustainable performance of buildings. It includes all of the final processes to hand over these green building projects to the building owner and facility management organizations.

Elizabeth et al. (2019) compare the economics of green buildings and traditional buildings and found that the cost of green buildings is higher than that of conventional buildings. The benefits will make it more cost-effective than conventional construction. Wang et al. (2019) introduce the specific application of BIM technology in the logistics operation management of green buildings from the aspects of space management, equipment monitoring management and energy saving benefit management, which concludes that BIM technology can significantly improve the efficiency of green building management. Han et al. (2019) investigate and analyze the current status and needs of green building project operations, and analyze the value of BIM technology application during the green building operation period from the value of BIM tools themselves, the value to operators and the value to managers. Zhou Yingwen et al. (2020) apply the BIM model to green commercial buildings, and analyze the operational requirements of green commercial buildings from asset management, equipment maintenance, alarm processing, security management, fire rescue and environmental control. Tahmasebinia et al. (2022) develop BIM-based lifecycle frameworks to bridge energy performance gaps and achieve sustainability goals for buildings such as reviewing designs, monitoring energy quality, real-time operations and maintenance management.

However, the application of relevant green BIM technology in this stage is not perfect. In this stage, BIM is mainly used to manage the operation of mechanical and electrical equipment, and to deal with sudden failure events, which is relatively limited. He et al. (2021) believe that green buildings will become the focus of the future development of the construction industry, but the current level of green building operation and maintenance management is low, and the post-operation management and maintenance are poor, resulting in low utilization of equipment used in green technology (Figure 10).

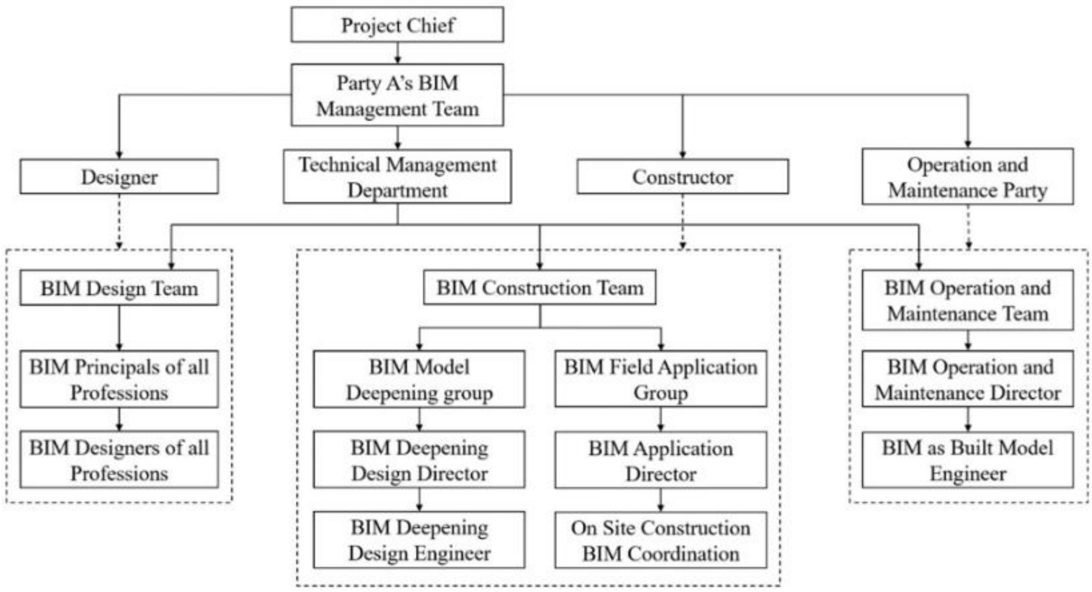


Figure 10. BIM-based information management team organization structure by He et al.

3.4 Green BIM as a Synergy Tool between BIM and GBCs

In the green building evaluation process that mainly relies on construction drawings and related texts, the evaluation applicant needs to submit a large amount of project data, and the evaluation experts need to repeat modeling in the simulation software when performing building performance simulation analysis. During the review process, the review and scoring of all items are manually carried out by evaluation experts, with heavy workload, low degree of automation, high error-proneness, and low efficiency. The growth of Green BIM reinforced the correlation between the growth of the green and sustainable certified building and the use of BIM tools.

Based on BIM technology for green building evaluation, a large amount of building information can be directly obtained in the model. Using BIM for green building certification is the research direction of many BIM software companies and scholars. The IFC standard that emerged to facilitate information exchange between different software in the construction industry helps many BIM software (such as Autodesk Revit Architecture, ArchiCAD, etc.) to directly output model information in a standard format. Some performance simulation software (IES-VE, Safaira, Ecotect analysis) can import these model information for performance simulation and provide evaluation materials for green building evaluation. Some BIM software companies, such as IES (Integrated Environmental Solutions), One Click and Autodesk, have developed a series of BIM-oriented technical tools for LEED® and BREEAM. The VE-Navigator module of IES supports the automatic evaluation of some of the credits of "thermal comfort", "daylight", "indoor environmental quality" and "optimize energy performance" in LEED® v4. IES supports the automated evaluation of the 'Management', 'Health' and 'Energy' modules of BREEAM. One-Click Life Cycle Assessment can support the evaluation of the LEED® V4 "Building Life Cycle Impact Reduction" module and the BREEAM (Mat 1) "Life Cycle Impact" module. The Revit plug-in Light Analysis Revit can realize the automatic evaluation of LEED® v4 EQc7 opt2.

According to the research of some scholars, some items in the green building evaluation system can directly or indirectly use the existing BIM technology to complete the evaluation. Based on BIM technology, quantitative assessment items are easier to evaluate than qualitative assessment items. According to analysis by Wong et al.(2016), 26 items in BEAM Plus in Hong Kong can be evaluated based on the files generated by BIM, among which 15 items can be evaluated through the schedule function of BIM software, and 11 items can be evaluated through BIM-based building performance simulation tools. Gandhi et al.(2014) study the current application status of BIM and Green Star, an Australian green building evaluation system in the industry, and conclude that in the field of non-residential building evaluation, 31 items in Green Star can be evaluated through the Revit model and the building performance simulation software based on the Revit model. Chen et al. (2018) integrate BIM and network map services, and develope a Revit plug-in tool for scoring the "Location and Transportation" item in LEED® by using the API tools of Revit and Google Map (Figure 11). Azhar et al. (2016) use IES-VE performance simulation on a real project to achieve LEED® scores for Energy and Atmosphere, Water Efficiency, and Indoor Environmental Quality.

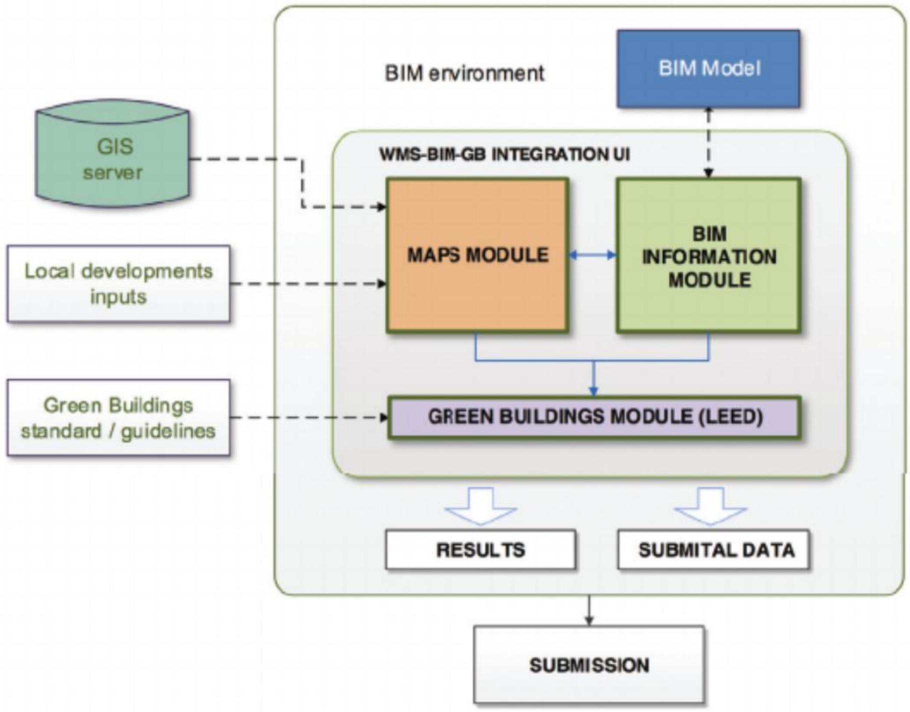


Figure 11. BIM-WMS-LEED integration framework by Chen et al.

3.5 Research Gap

At present, no organization or individual has developed a green building evaluation technology tool based entirely on BIM technology. Maybe there are several reasons for that:

1. The evaluation of green buildings is based on an authoritative standard. The authoritative standard will be updated continuously with the changes of time, the update of green building technology and the change of people's cognition of green buildings. This update is not limited to data, sometimes structural changes occur. Once this change occurs, the integration of standards and BIM has to be done all over again.
2. Some qualitative items in green building evaluation, such as "innovation", require professionals to use their own experience to make subjective judgments.
3. In some areas, the application level of BIM technology is low, and the construction industry still mainly relies on traditional 2D design. At present, the research on green building evaluation relying on BIM is still at the stage where some items are being discussed.

In addition, simulation-based methods work well in calculating energy consumption under different design parameter settings, but manually adding such a large number of building parameters into a BIM-based simulation engine takes a lot of time. For example, Li et al.(2017) combine discrete event simulation with an optimization algorithm to successfully reduce CO2 emissions caused by on-site construction in cold regions. Tushar et al. (2021) develope a BIM-based integration of life cycle analysis and energy simulation to optimize and get useful design strategies that can comprehensively improve the energy efficiency and environmental impact of buildings (Figure 12). However, according to the questionnaire survey conducted by Huang et al.(2021) among different stakeholders, some obstacles to green BIM practice still need to be addressed, such as inconsistencies in existing regulations/standards, high requirements for BIM technical training, excessive manual operations, and insufficient data utilization, etc. Panagiotidou et al.(2022) consider data exchange and collaboration to be one of the most difficult tasks, with limitations mainly in the exchange of data in different softwares, which is affecting the speed at which these methods are adopted in the construction industry (Figure 13). Furthermore, Aksenova et al.(2019) believe Building Information Modeling (BIM) platforms should develop specific functionality for ecosystem professionals to pretend to work together and add new value to projects.

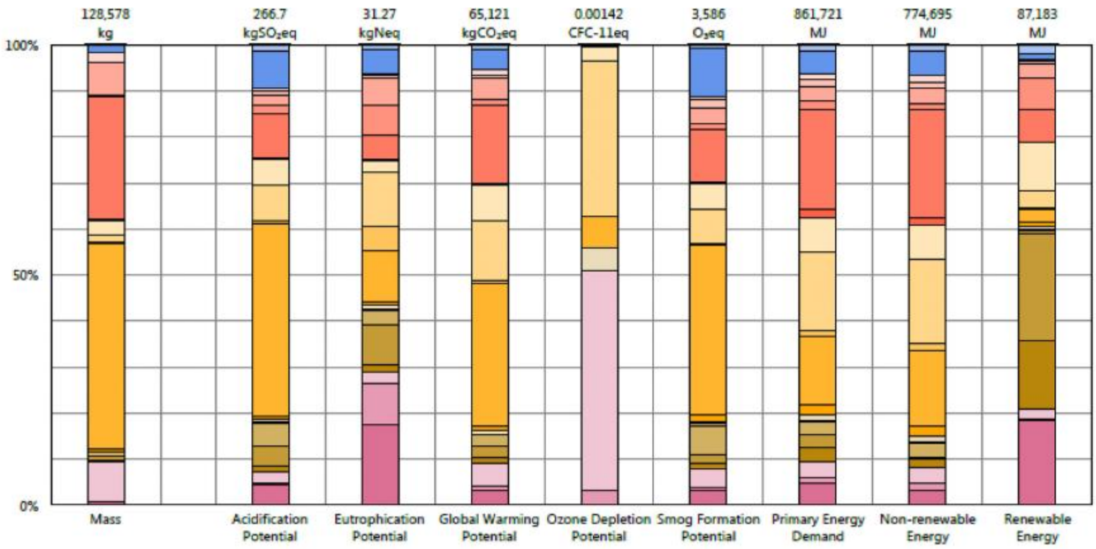


Figure 12. Embodied environmental impact categories by Tushar et al.

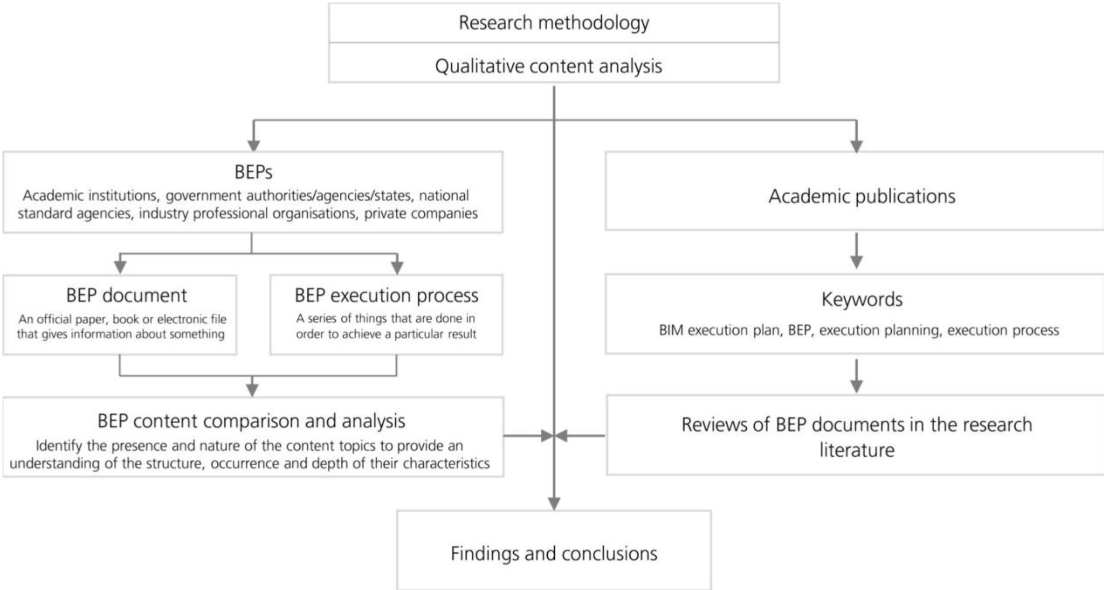


Figure 13. Qualitative content analysis diagram by Panagiotidou et al.

In other words, the potential of BIM in the development of green buildings has not been fully realized. As BIM has become a digital solution in information management, there is space for improvement in fully utilizing BIM-related data for sustainable design and performance analysis.

4 Purpose of the Study, Scope and Methodology

4.1 Research Purpose

From the BIM concept proposed by Autodesk in 2002 to now, the application of BIM in the construction industry has become more and more extensive and in-depth. BIM has been widely recognized around the world and is regarded as a major revolution in the construction industry. Various green building evaluation standards clearly include the design, construction, operation and maintenance of new projects into the integrated application of BIM technology, and specifically propose that BIM technology should be used to carry out building performance analysis including energy-saving, sunlight, wind environment, light environment, acoustic environment, thermal environment and traffic.

Based on the above background, the research will focus on green building performance simulation analysis and statistics based on BIM platform, including building energy consumption analysis, full life cycle analysis, light environment analysis, modeling information summary and statistics. The goal is to combine the BIM applications currently being promoted with green building performance analysis, and explore how to use the advantages of informatization and integration of BIM technology to connect and analyze the building information model established using BIM technology with various building performance analysis software. Calculation enables architects to conduct simulation analysis of green building performance more conveniently and quickly. The sharing building information model established by BIM technology can keep the design model consistent with the analysis model, improve the accuracy of green building performance analysis, and better guide the design. The study also researches on how to integrate green building design into the larger framework of BIM technology application, expand the application scope of BIM, and look forward to sorting out a set of work processes based on BIM technology design, simulation, evaluation, and optimization.

4.2 Research Methodology

For this study, a three-step methodology is introduced below.

The first step is the construction of the 3D model for the target building. With the use of BIM, the different kinds of engineering information of the original building can be transferred and integrated to BIM-related tools like Revit in different formats for the following statistics and simulations;

The second step is the development of the conceptual framework for establishing the relationship between BIM and LEED® rating processes which can better prepare for assessing green building performance and optimization. This framework was developed based on literature review including identifying key factors and weights for the environmental performance;

The third step is the validation of the developed framework via a case study in the following sections. The statistics and simulations can be realized in BIM-related tools and projects can evaluate and optimize performance by incorporating required evaluation standards. Figure 14 shows the workflow for the research methodology and the detailed process and results of the three steps will be presented in the following sections.

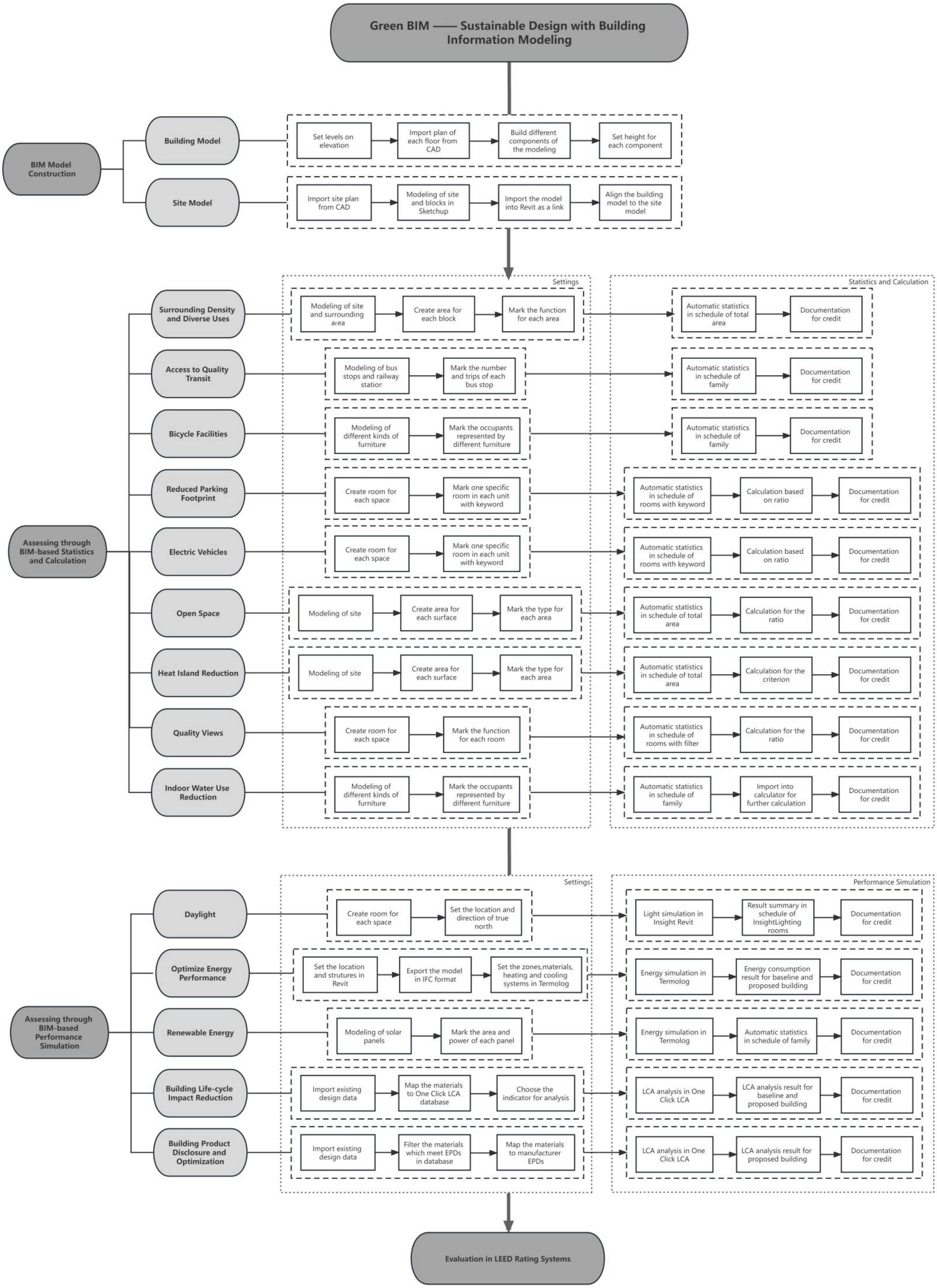


Figure 14. Workflow for the research methodology

5 BIM Model Development in a Case Study

5.1 Case Background

The aim of the project is to design a building complex for residential use (special student residence) in an area of urban renewal. The development of the design follows the three levels of building design in accordance with Italian law with regards to public works (1 - feasibility study; 2 - definitive design; 3 - constructive design).
As for the site, the intervention will be located in an area of decommissioned railway land at the ex Rogoredo railway station as shown in Figure 15. The land is listed as an area of urban renewal (ATU) by the PGT (Piano di Governo del Territorio) of Milan.
The Urban Renewal Area “Rogoredo” will be characterised by close ties to different green areas, in existence and planned, using useful connections for the environmental network which features in the south west of the city. The areas involved include the “Parchi delle Cascine”, the “Collana Verde” and the “Ronda” as well as the existing Alessandrini Park. The central nature of the public space, designed to support the connections to various environmental systems, will have the capacity to define the location of the planned new facilities close to Rogoredo station. In LEED® standard, the site can be categorized as protective site and high priority site.

Figure 15. Site of the project at Rogoredo station

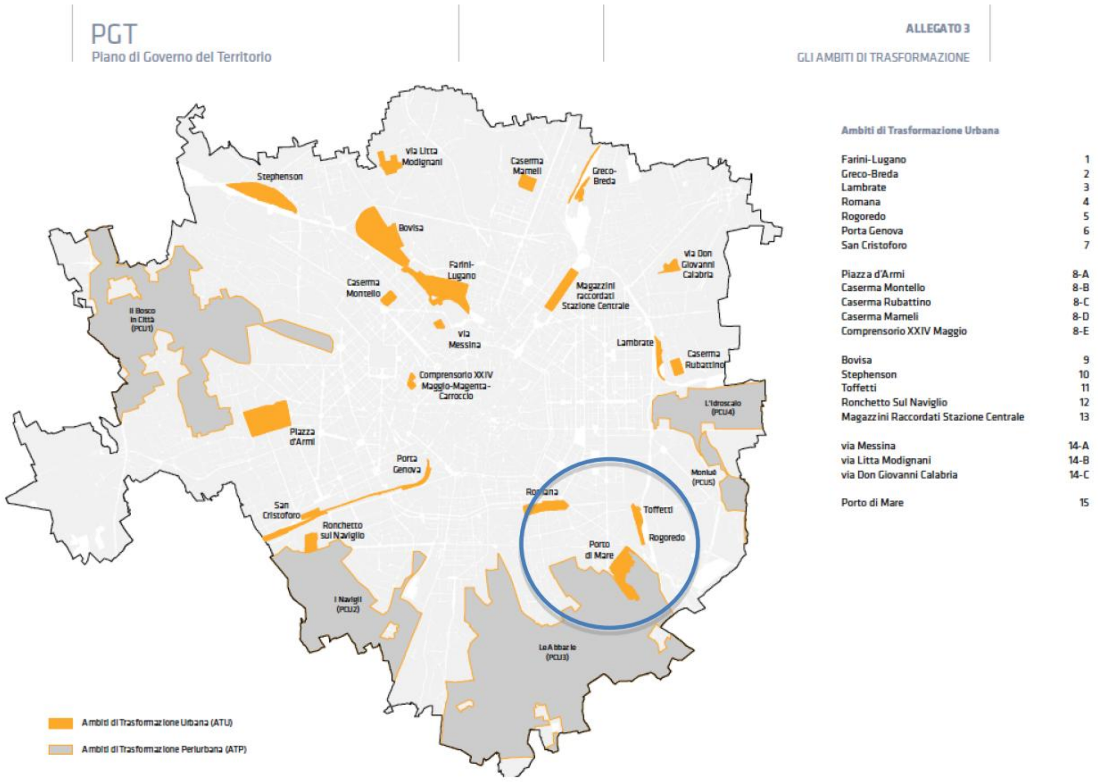


Figure 16. Area 'Rogoredo' in PGT of Milan

The construction programme provides for the design of a student residence with the following dimension parameters as shown in Table 3, including student residence, common functions, parking areas and green spaces. For the site, Figure 17, 18 show the whole project consisting of the student residence building and two social houses. The surrounding green parks and a green hill around the traffic nodes are designed as the buffer space and provide better environment and comfortable visual effects. A public road across the site and a bridge across the railway are designed for better traffic and connection for the whole area from east to west.

Table 3

Student residence project description.

Item	Description
Project	Student residence at Rogoredo Station
Territory surface	10566 m^2
Building surface	12884 m^2
Student residential area	9626 m^2
Other functions area	3258 m^2
Levels	11 floors with 1 floor basement
Public parking	200 m^2
Private parking	1500 m^2
Public green spaces	3894 m^2

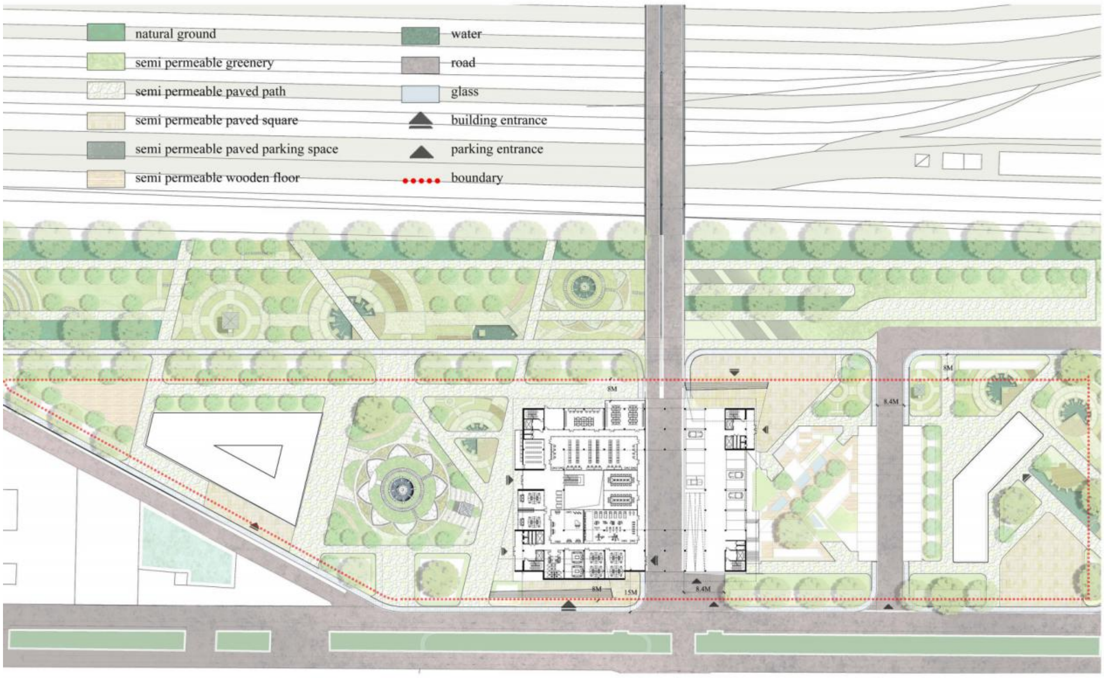


Figure 17. Site plan of the project

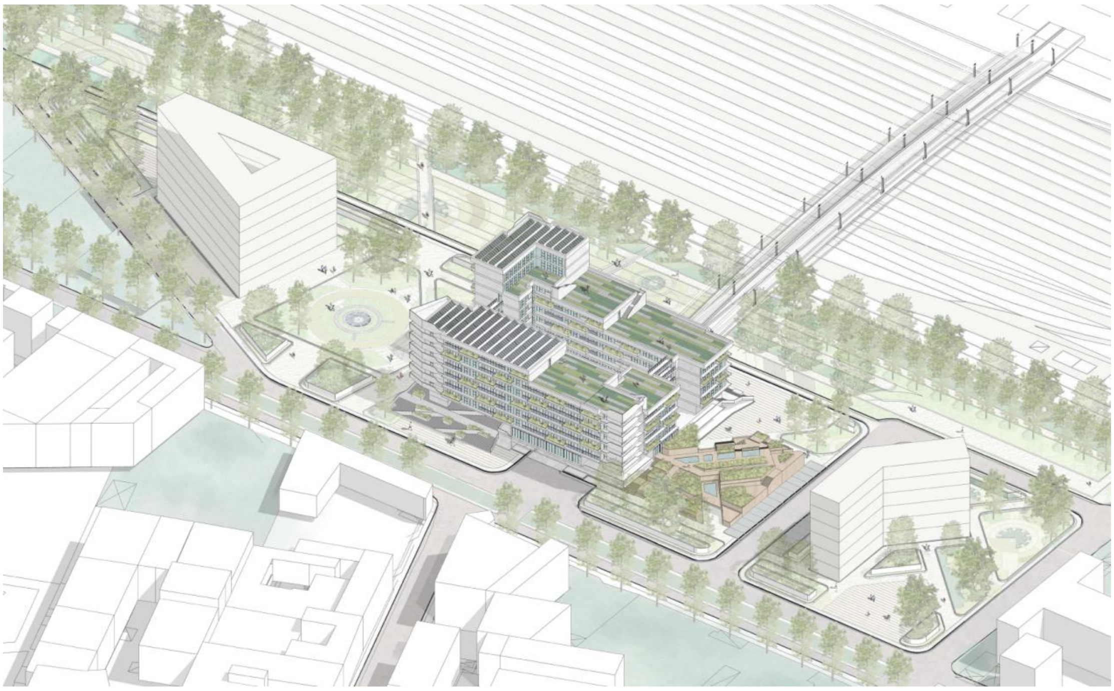


Figure 18. Bird view of the whole project

For the student residence, it has 6 kinds of residential spaces as shown in Figure 19, in which 50% of the spaces for hotel type solution, 20% of the spaces to mini-residence type and 30% of the spaces to integrated accommodation type. Figure 20 shows the function distribution of the typical floor.

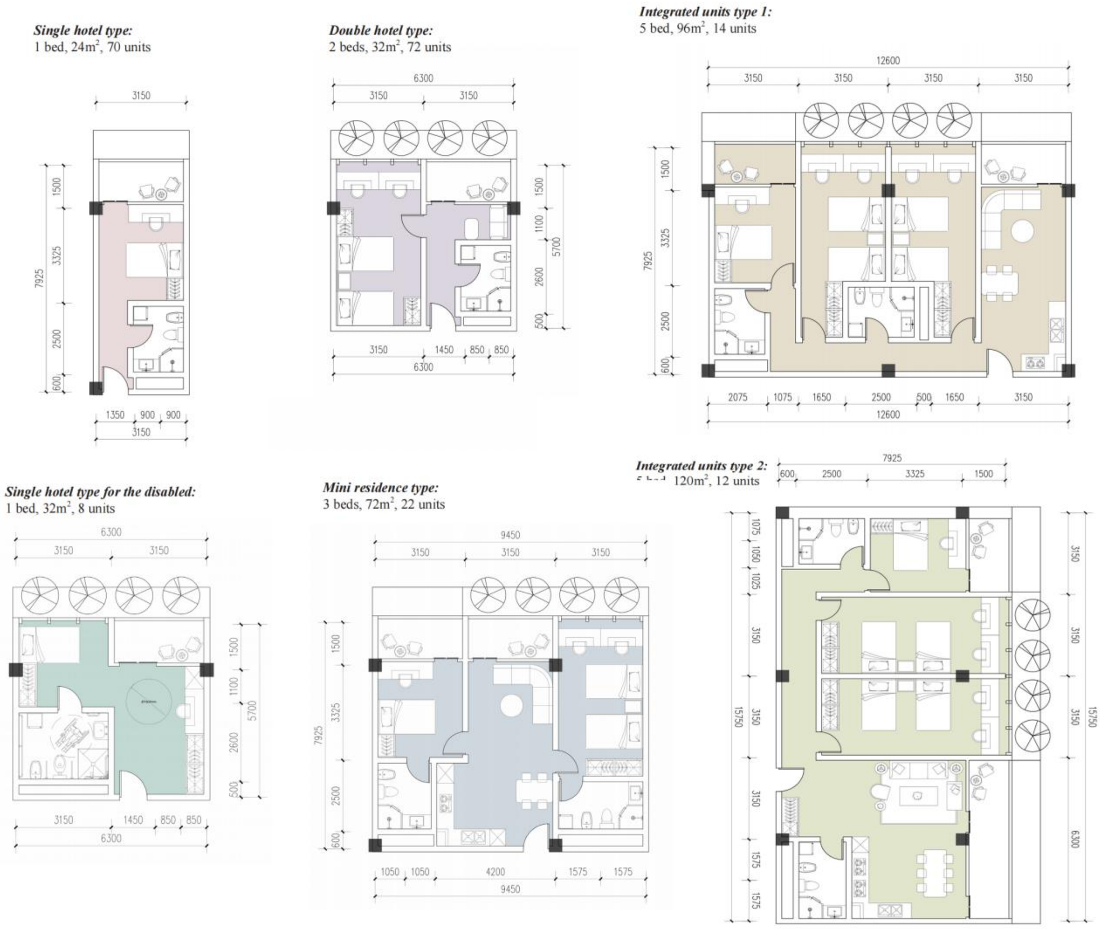


Figure 19. Six kinds of residential spaces

Figure 20. Function distribution of the typical floor

As an important element in LEED® evaluation, the functional area is provided for student residence and guests for the area. For the functional area, it consists of cultural and teaching facilities, recreation facilities, management and administrative services, circulation, car parking and technical rooms. The detailed layout for different functions and their connection with the entrances on the ground and first floor are shown in Figure 21, 22.

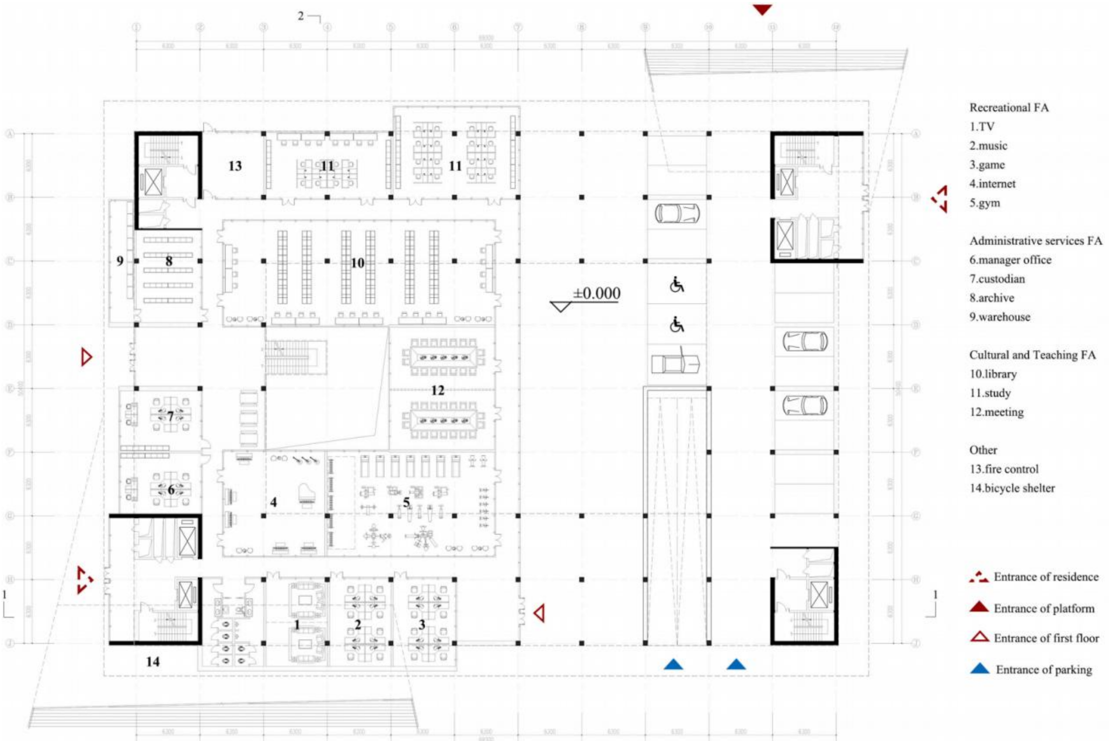


Figure 21. Function distribution of the ground floor

Figure 22. Function distribution of the first floor

Figure 23 shows some facade details of the building. The windows on the facade use double pane low-e glass on west, north and east, but use clear glass on south for maximum passive solar gain. Outside the windows, the overhanging floor slab and the green plant box are designed as slopes to reflect the noise coming from the road and provide shading for the rooms. As for the balcony, it can extend living areas in cool weather, and the green box on it can increase the greening rate and refresh the air.

Figure 23. Facade details on windows, cantilever and balcony

5.2 BIM Model Construction

The BIM software for the modeling of the project is Revit. Revit allows for entire buildings or parts of buildings to be modeled and worked on, which is very useful for all parties involved in construction projects. Using Revit modeling as part of the BIM process eases the creation of 3D renders, 3D perspectives, detailed drawings and walkthroughs.

The work of modeling can be divided into two parts, which are the modeling of the building itself and the modeling of the site. For the modeling of the building, the first step is to set several levels on the elevations. On each level, the plan of each floor can be imported in dwg format as Figure 24 shows. The axes can be located based on the plan and different components of the modeling like floors, walls, windows and doors can also be built on the reference plan. The height of each component is based on the height of each level and the facades. Figure 25 shows the rendering of the building with levels and axes in Revit.

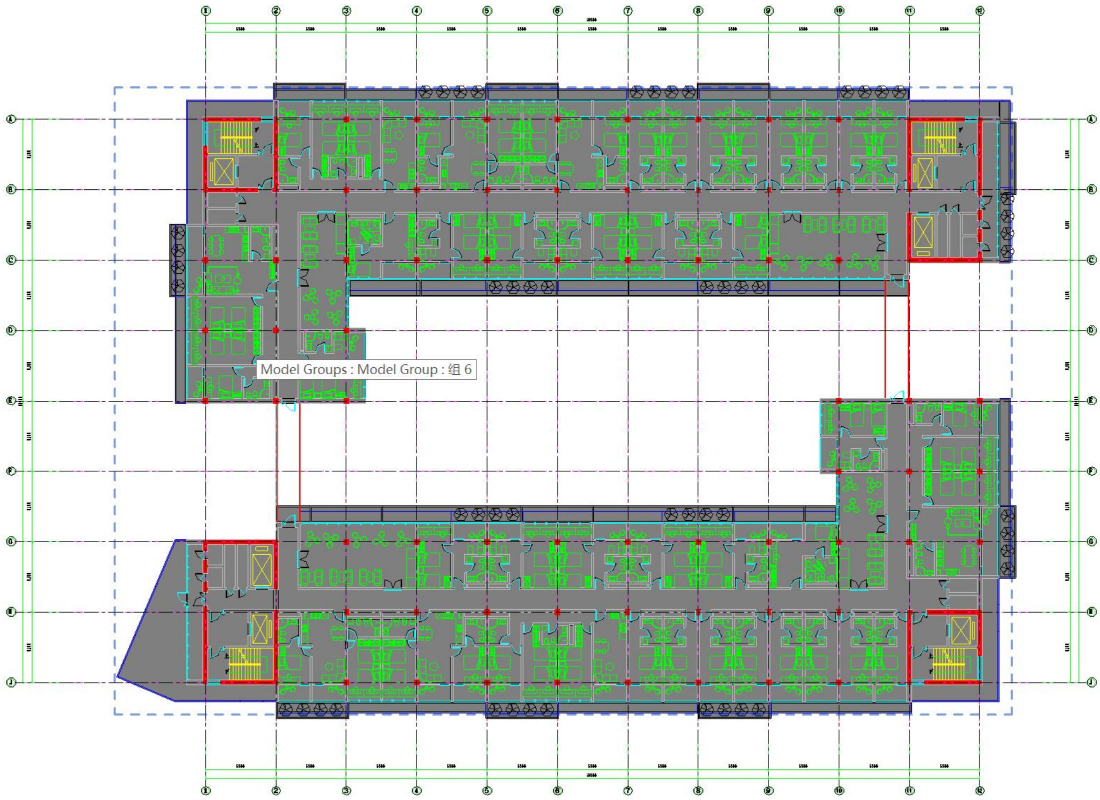


Figure 24. Reference plan imported into Revit

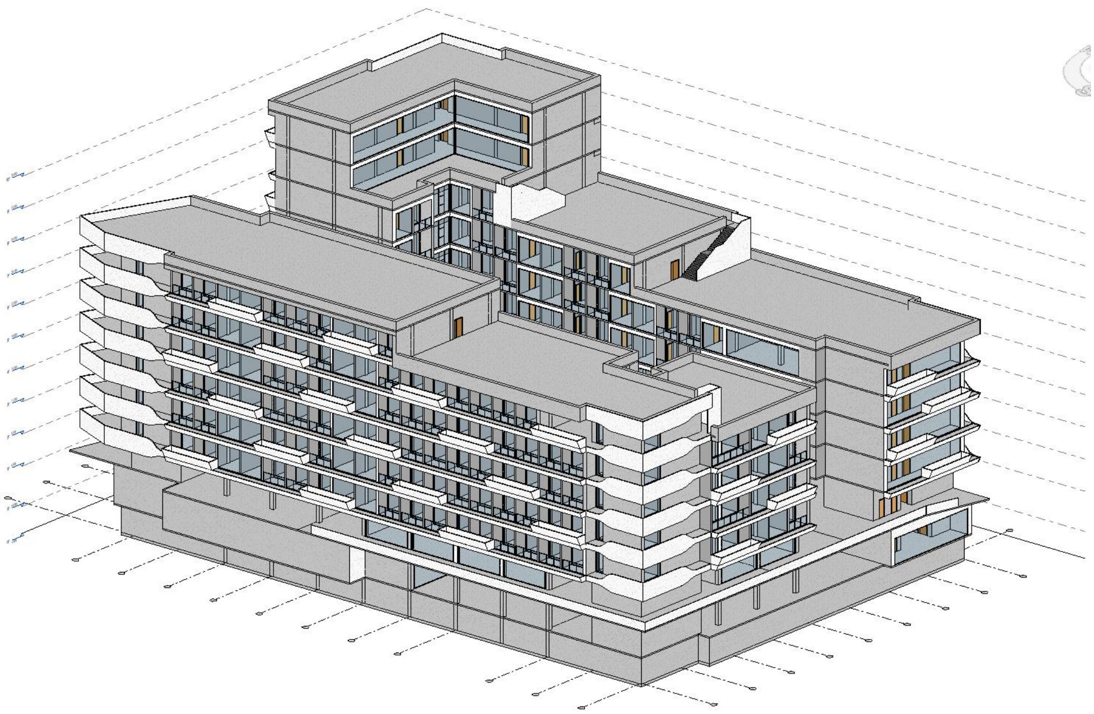


Figure 25. Southwest rendering of the building

For the modeling of the site, since the modeling of the site is only used as the reference for statistics and to reduce the size of the whole document, the model of surrounding blocks and design of open spaces is firstly built in Sketchup as Figure 26 shows and then imported into Revit as a link which can always be renewed. After that, the model of the building can be aligned to the site model and Figure 27 shows the southwest rendering of the whole project.

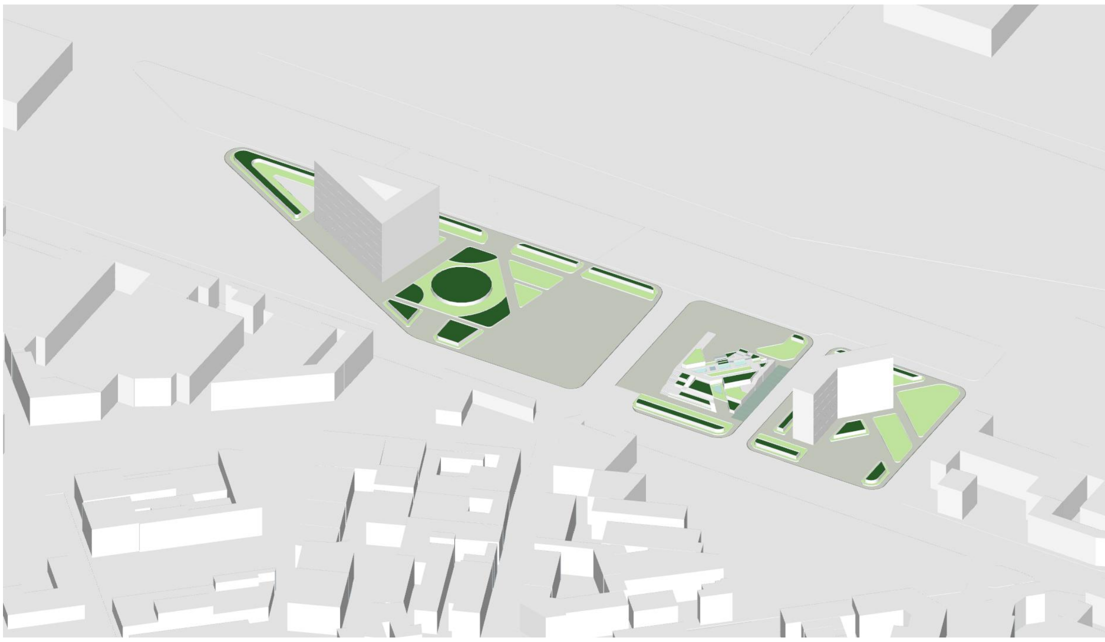


Figure 26. Site and surrounding model in Sketchup

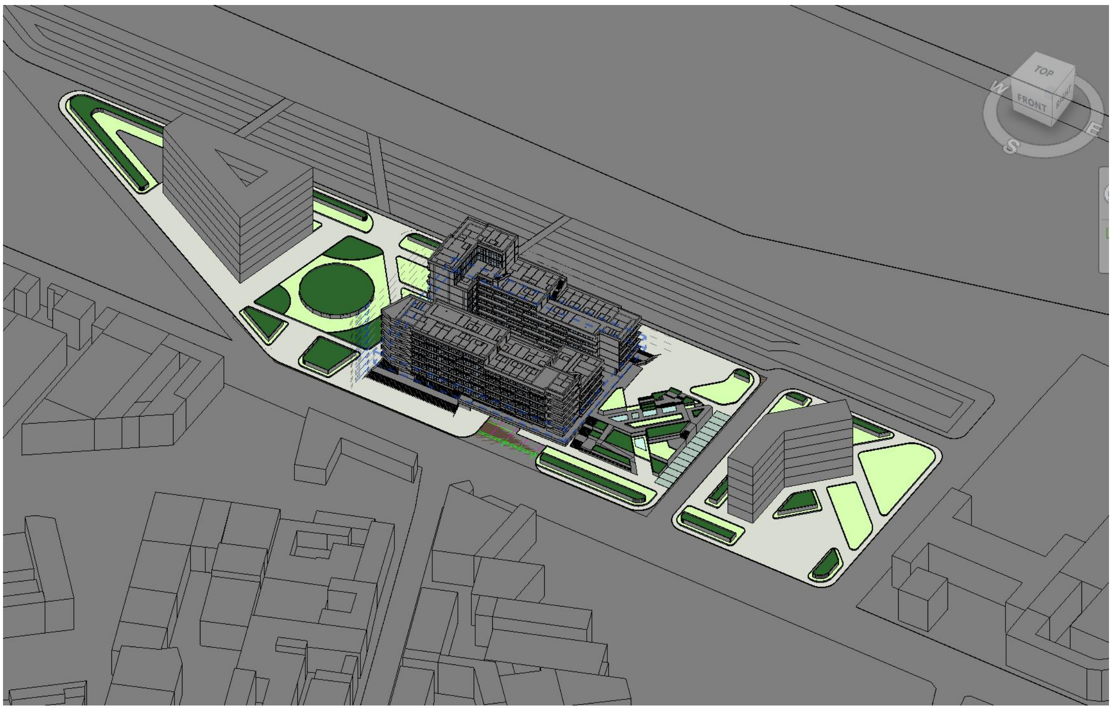


Figure 27. Southwest rendering of the whole project

6 Assessing Buildings Compliance with LEED® Rating Systems through a BIM-based Approach in a Case Study

6.1 Conceptual Framework for Establishing a Relationship between BIM and LEED® Rating Processes

Based on the review of existing literature, in this research, the conceptual framework prepared to illustrate the relationship between various LEED® credits and associated BIM-based sustainability analyses is mainly divided into two parts: BIM for statistics and calculation and BIM for performance simulation.
This framework will be validated using data from a case study which is discussed in the following section. The presented case study also identifies the number of LEED® credits for which required documentation can be prepared using results of BIM-based sustainability analyses.

6.2 Assessing through BIM-based Statistics and Calculation

6.2.1 Schedule and Quantities

The BIM-based statistics and calculation is realized through the module Schedule and Quantities (Figure 28) in Revit. Revit schedules are usually created because there is a need to quantify the various elements in the Revit project. Revit schedules are a lot like a spreadsheet. They consist of columns and rows and the cells contain various data regarding the Revit elements. On top of that formulas and parameters can be applied to calculate new values from existing ones.

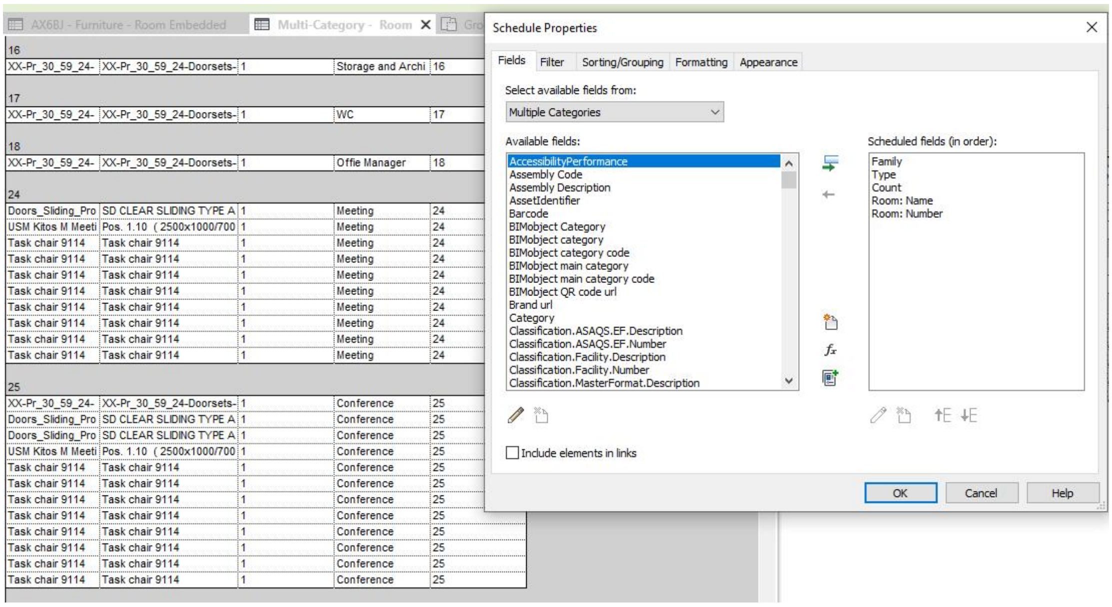


Figure 28. Schedule and Quantities in Revit

6.2.2 LT Credit: Surrounding Density and Diverse Uses

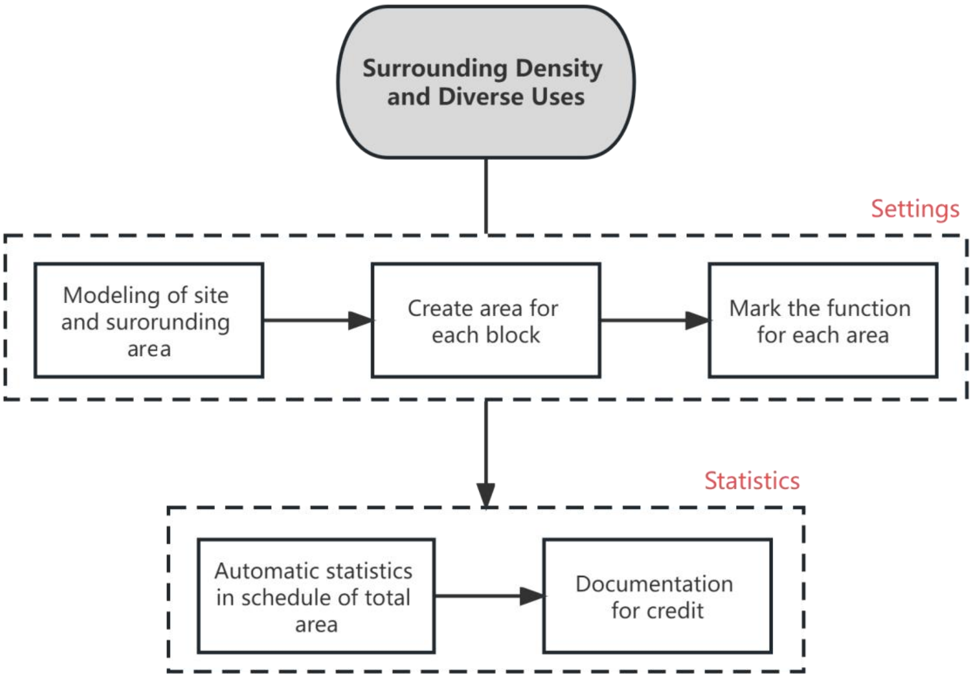


Figure 29. Workflow for the credit

The intent of the credit is to conserve land and protect farmland and wildlife habitat by encouraging development in areas with existing infrastructure. In addition, it helps to promote walkability, transportation efficiency, reduce vehicle distance traveled and improve public health by encouraging daily physical activity.
The credit rewards the site whose surrounding existing density within a 1/4-mile (400-meter) offset of the project boundary meets the values in Table 4 and the building's main entrance is within a 1/2-mile (800-meter) walking distance from the number of uses in the guide as Table 5, 6 shows.

Table 4

Points for average density within 400 meters of project (SI units).

Combined density	Separate residential and nonresidential densities		Points BD+C (except Core and Shell)	Points BD+C (Core and Shell)
Square meters per hectare of buildable land	Residential density (DU/hectare)	Nonresidential density (FAR)		
5,050	17.5	0.5	2	2
8,035	30	0.8	3	4

DU = dwelling unit; FAR = floor-area ratio.

Table 5

Points for proximity to uses.

Uses	Points
4-7	1
⩾8	2

Table 6

Use Types and Categories.

Category	Use type	Category	Use type
Food retail	Supermarket	Civic and community facilities	Adult or senior care (licensed)
	Grocery with produce section		Child care (licensed)
Community-serving retail	Convenience store		Community or recreation center
	Farmers market		Cultural arts facility
	Hardware store		Education facility
	Pharmacy		Government office that serves public on-site
	Other retail		Police or fire station
Services	Bank		Post office
	Family entertainment venue (e.g., theater, sports)		Public park
	Gym, health club, exercise studio		Social services center
	Hair care		Place of worship
	Laundry, dry cleaner	Community anchor uses (BD&C and ID&C only)	Housing (100 or more dwelling units)
	Restaurant, café, diner (excluding those with only drive-thru service)		Commercial office (100 or more full-time equivalent jobs)

For the evaluation of the project, first the modeling of the site and surrounding areas is built in Revit based on the dwg file of the whole region like Figure 30 shows. Then the panel of Area in Revit is used to identify and calculate the floor area of each surrounding block within 400-meter offset of the project boundary in the plan of ground floor. In Figure 32, each area is marked as its function according to the use types and categories defined by LEED® protocol. Finally, in the schedule of total area, the total floor area and number of blocks of different functions can be counted automatically.

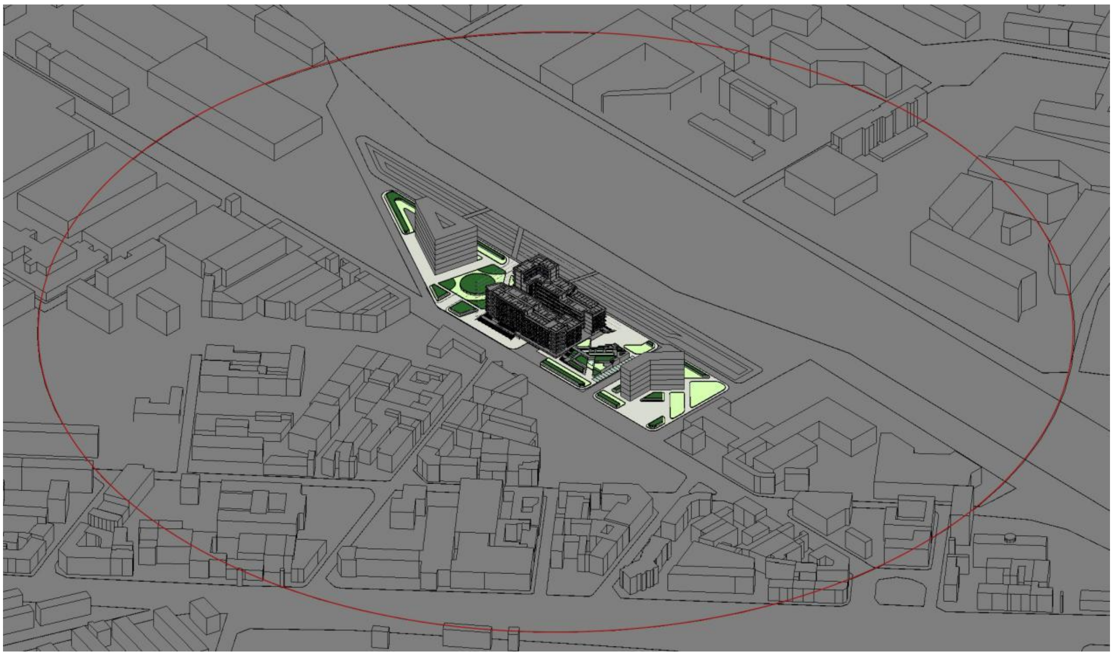


Figure 30. Modeling of the site and surrounding areas

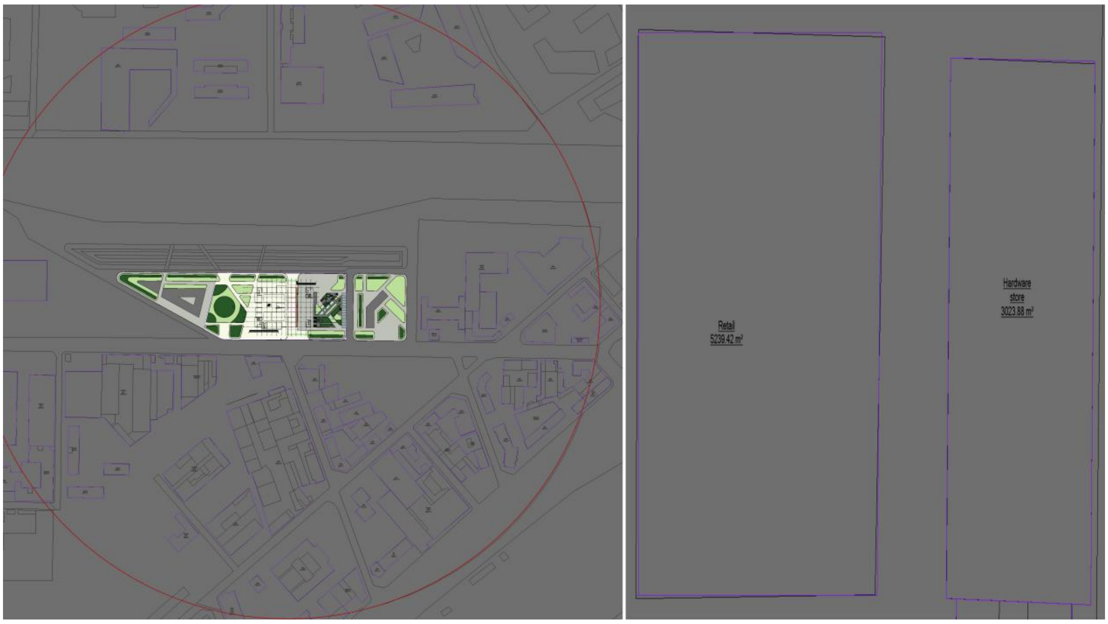


Figure 31. Areas marked according to functions

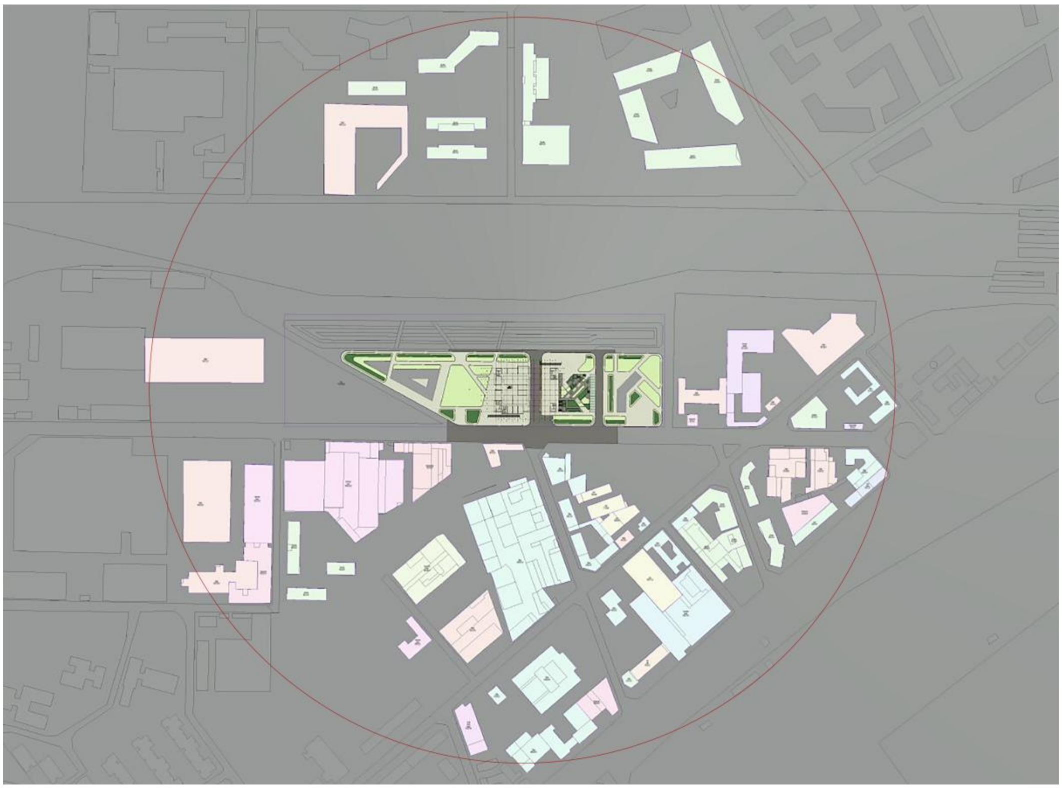


Figure 32. Different colors marked according to functions

The result can be exported into Excel and used as the documentation for the credit like Table 7 shows. For the project, in Option 1 of surrounding density, the combined density within 400 meters of project is 11,115 square meters per hectare of buildable land which is over 8,035 square meters in the requirement and can achieve 3 points. And in Option 2 of diverse uses, since there are 15 uses in total, which is over 8 uses in the requirement, the project can achieve 2 points. And in total, the project can achieve 5 points in this credit.

Table 7

Result for surrounding density and diverse uses.

<Surrounding areas>			
A	B	C	D
Name	Level	Area（square meters）	Total
Bank	0F	973	2
Community center	0F	3502	1
Education facility	0F	5869	1
Entertainment	0F	2619	1
Farmers market	0F	3871	1
Gym	0F	4246	4
Hair care	0F	703	1
Hardware store	0F	14796	3
Housing	0F	27019	18
Office	0F	27425	14
Post office	0F	676	1
Restaurant	0F	4788	4
Retail	0F	33381	12
Site	0F	57744	1
Social sevice center	0F	1233	1
Supermarket	0F	150	1

6.2.3 LT Credits: Access to Quality Transit

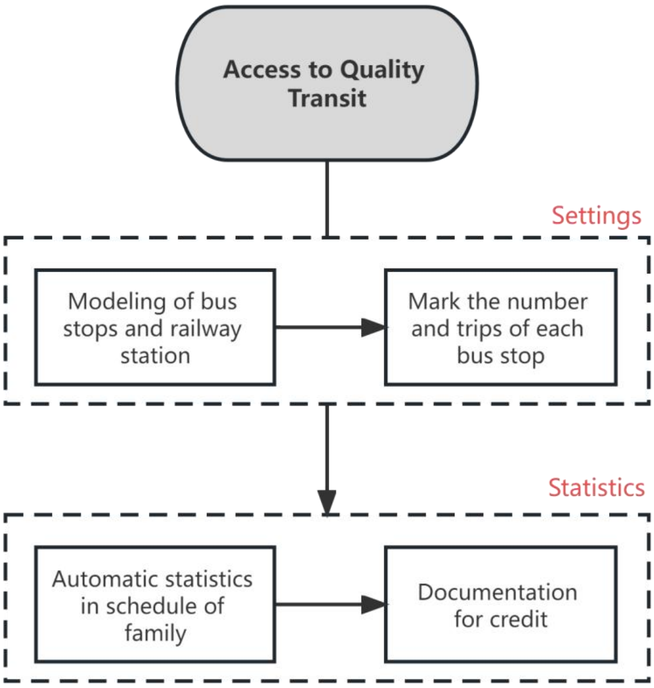


Figure 33. Workflow for the credit

The intent of the credit is to encourage development in locations shown to have multimodal transportation choices or otherwise reduced motor vehicle use, thereby reducing greenhouse gas emissions, air pollution, and other environmental and public health harms associated with motor vehicle use.

The credit rewards the project which locates any functional entry within a 1/4-mile (400-meter) walking distance of existing or planned bus stops, or within a 1/2-mile (800-meter) walking distance of passenger rail stations (i.e. light, heavy, or commuter rail) or commuter ferry terminals. The transit service at those stops and stations must meet the minimum requirement as Table 8 shows.

Table 8

Minimum daily transit service.

Weekday trips	Weekend trips	Points BD+C (except Core and Shell)	Points BD+C (Core and shell
72	30	1	1
100	70	2	2
144	108	3	3
250	160	4	4
360	216	5	6

For the evaluation of the project, based on the existing model, the bus stop components from the libraries of the Revit are set into the model according to their real locations which are within 400-meter walking distance from the entry of the project in the plan of ground floor. Then the columns of line number, weekday trips and weekend trips of the bus stops are created and marked inside the property of each component. Finally, in the schedule of the family of bus stops, the properties of each bus stop and railway station like weekday and weekend trips are collected.

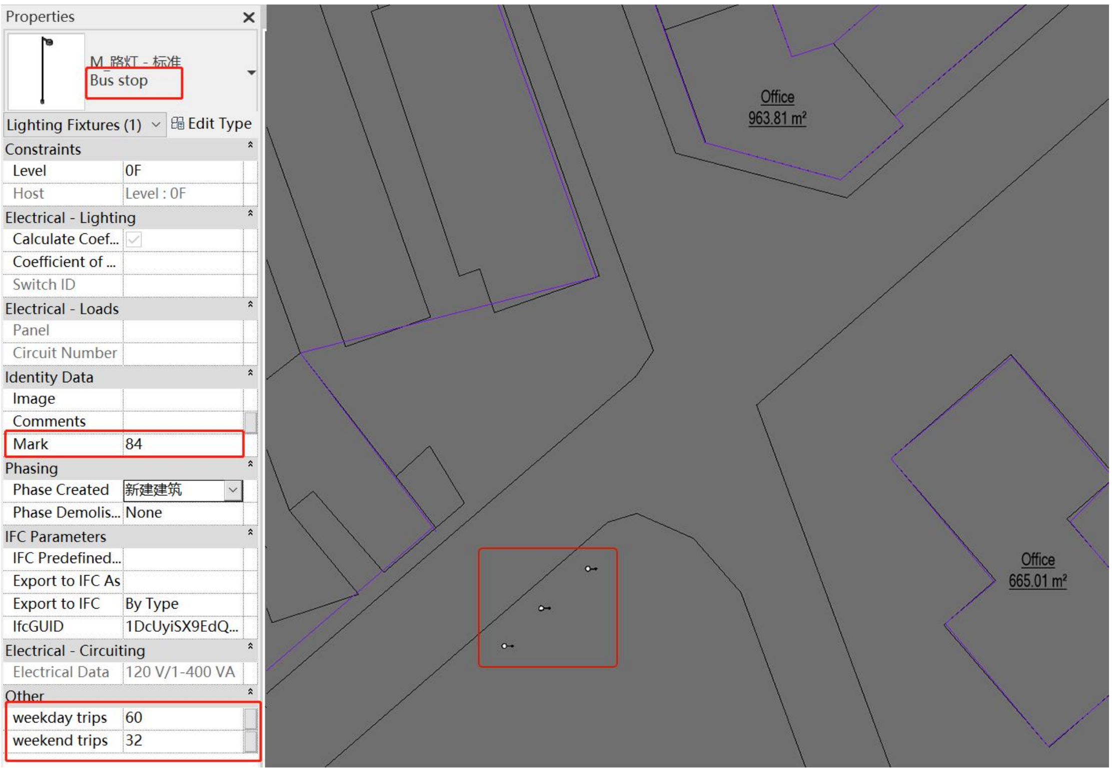


Figure 34. Bus stops in the Revit model

The result can be exported into Excel and used as the documentation for the credit as shown in Table 9. For the project, there are 999 weekday trips and 665 weekend trips in total by 7 bus stops and 1 railway station. Since the total numbers are over than 360 weekday trips and 216 weekend trips in the guide, the project can achieve 5 points in this credit.

Table 9

Result for weekday trips and weekend trips.

<Bus Stop>					
A	B	C	D	E	F
族	type	mark	weekday trips	weekend trips	total
M_路灯 - 标准	M_路灯 - 标准: Bus	NM3	12	12	1
M_路灯 - 标准	M_路灯 - 标准: Bus2	M3	204	192	1
M_路灯 - 标准	M_路灯 - 标准: Bus3	Train station	270	180	1
M_路灯 - 标准	M_路灯 - 标准: Bus stop	88	75	33	1
M_路灯 - 标准	M_路灯 - 标准: Bus stop	66	114	72	1
M_路灯 - 标准	M_路灯 - 标准: Bus stop	84	60	32	1
M_路灯 - 标准	M_路灯 - 标准: Bus stop	95	120	76	1
M_路灯 - 标准	M_路灯 - 标准: Bus stop	93	144	68	1

6.2.4 LT Credits: Bicycle Facilities

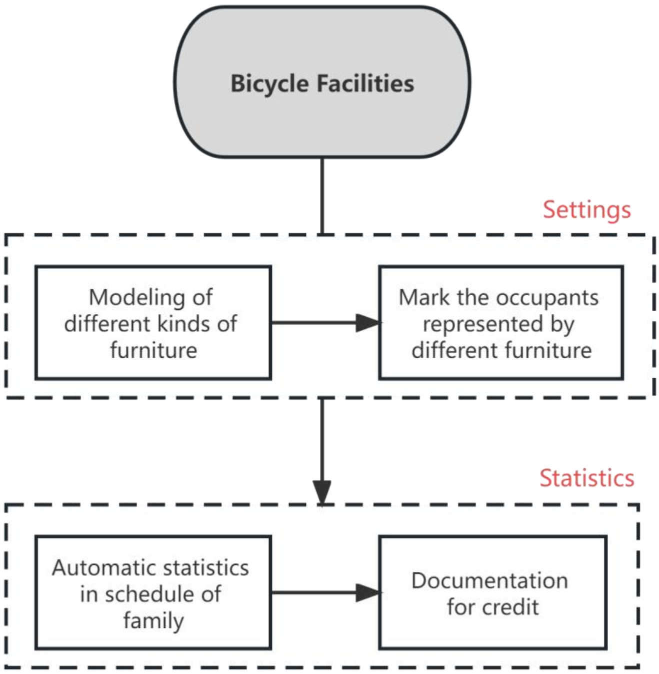


Figure 35. Workflow for the credit

The intent of the credit is to promote bicycling and transportation efficiency and reduce vehicle distance traveled. In this way, public health can be improved by encouraging utilitarian and recreational physical activity.

The credit rewards the project whose entry or bicycle storage is within 180-meter distance from a bicycle network that connects to at least 10 diverse uses. In addition, for the residential projects, they need to provide short-term bicycle storage for at least 2.5% of all peak visitors but no fewer than four storage spaces per building. In addition, they need to provide long-term bicycle storage for at least 15% of all regular building occupants, but no less than one storage space per three residential units.

For the evaluation of the project, in Credit: Surrounding density and diverse uses, the existing bicycle network around the site has already connected to over 10 diverse uses. For the statistics of the number of peak visitors and regular building occupants, different kinds of furniture like chair, desk and bed are inserted into the model based on their real quantity to represent different occupancy types as Figure 36 shows and the schedule can be used to count the number of each kind of furniture for the statistics of each occupancy type separately.

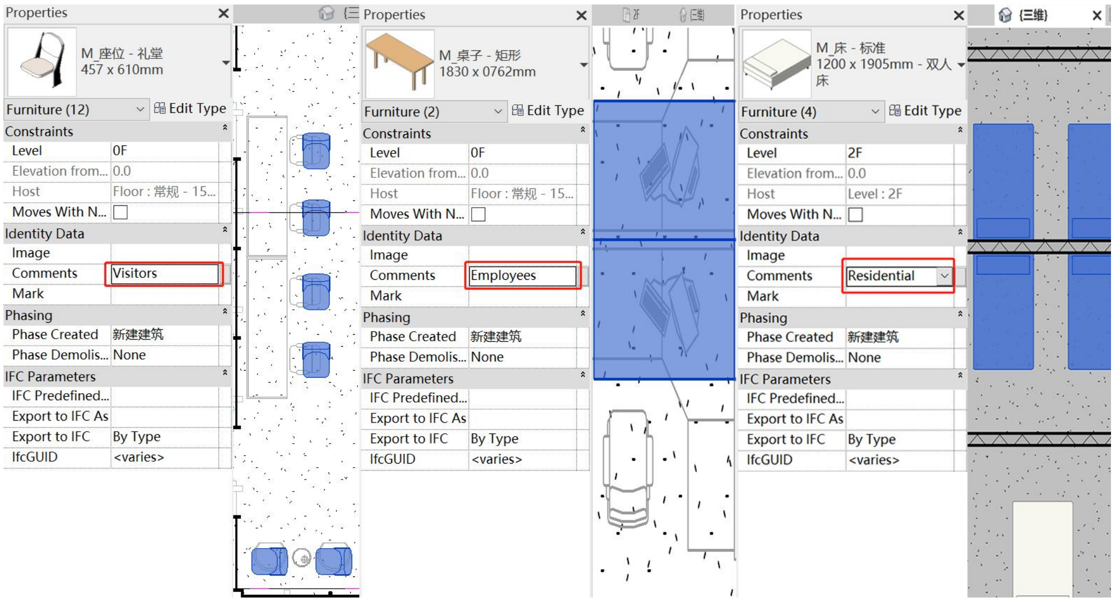


Figure 36. Different furniture to represent different occupancy types

The result can be exported into Excel as Table 10 shows. In the Excel, the total number of visitors counted in Revit can multiply by 2.5% and the requirement of short-term bicycle storage is 8.2 which is over than 4. The total number of regular building occupants can multiply by 15% and the requirement of long-term bicycle storage is 59.85 which is over than one storage space per three residential units. So in the project, there should be at least 9 short-term bicycle storage and 60 long-term bicycle storage to achieve 1 point in this credit.

Table 10

Result for number of occupancy and bicycle storage spaces.

Bicycle storage		
Occupancy type	Number	Bicycle storage spaces
Visitors	328	8.2
Residential	399	59.85

6.2.5 LT Credits: Reduced Parking Footprint

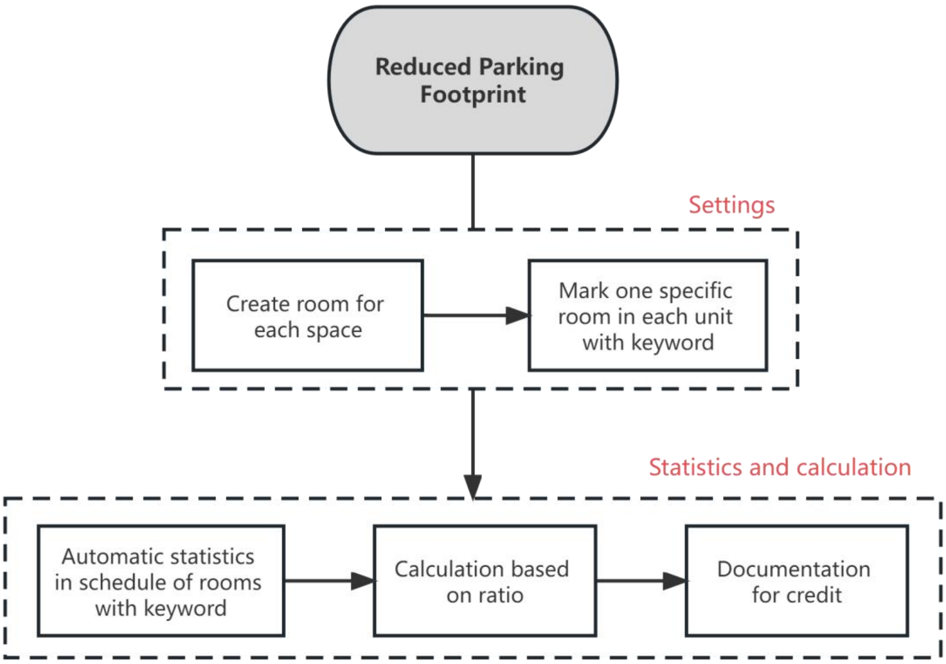


Figure 37. Workflow for the credit

The intent of the credit is to minimize the environmental harms associated with parking facilities, including automobile dependence, land consumption, and rainwater runoff.

The credit rewards the project which provides parking capacity that is a 30% reduction below the base ratios recommended by the Parking Consultants Council, as shown in the Institute of Transportation Engineers' Transportation Planning Handbook, 4th edition, Table 11-12. Table 11 shows the parking generation and recommended parking ratios.

Table 11

Parking generation and recommended parking ratios.

ITE Code	Use		Period	# Studies	Coefficient of Variation	R^2	33rd Percentile		Average		85th Percentile		Unit	PCC *Recommended Zoning Ordinance Provisions* (2006)*
		ITE *Parking Generation* (Third Edition, 2004)					Parking Gen Rate in Peak Hour of Observations							
021	Commercial Airport	Daily	Weekday	16	45%	0.99	0.26		0.40		0.61		Enplanements	
		Daily	Saturday	9	71%	0.61	0.51		0.84		1.48		Enplanements	
		Daily	Sunday	7	54%		0.37		0.57		0.92		Enplanements	
093	Light Rail Transit with Parking	Suburban	Weekday	30	86%		0.07		0.14		0.21		Daily Boardings	
		Urban	Weekday	10	53%	0.64	0.04		0.06		0.09		Daily Boardings	
110	General Light Industrial		Weekday	7	44%	0.81	0.53	(0.49)	0.81	(0.75)	1.22	(1.13)	100 sq m (ksf GFA)	
			Weekday	5	32%	0.99	0.53		0.64		0.81		Employees	
130	Industrial Park		Weekday	11	49%		0.97	(0.90)	1.37	(1.27)	1.99	(1.85)	100 sq m (ksf GFA)	1.99 /100 sq m (1.85/ksf) GFA
			Weekday	8	27%	0.66	0.83		0.89		0.98		Employees	
140	Manufacturing		Weekday	3	23%		0.99	(0.92)	1.10	(1.02)	1.27	(1.18)	100 sq m (ksf GFA)	
			Weekday	3	24%		0.88		0.97		1.14		Employees	
150	Warehousing		Weekday	13	73%	0.87	0.30	(0.28)	0.44	(0.41)	0.72	(0.67)	100 sq m (ksf GFA)	0.72/100 sq m (0.67/ksf) GFA
			Weekday	13	33%	0.86	0.81		0.78		1.01		Employees	
151	Mini-Warehouse		Weekday	5	46%	0.88	0.14	(0.13)	0.17	(0.16)	0.22	(0.20)	100 sq m (ksf GFA)	1.75/100 Units
			Weekday	5	27%	0.92	1.18		[illegible]		[illegible]		[illegible]	
210	Single-Family Detached Housing		Weekday	6	18%	0.69	1.67		1.83		2.14		Dwelling Units	2/dwelling unit
221	Low/Mid-Rise Apartment	Suburban	Weekday	19	26%	0.93	1.09		1.20		1.46		Dwelling Units	
		Urban	Weekday	12	22%	0.95	0.92		1.00		1.17		Dwelling Units	*1.65/dwelling unit rental; 1.85/dwelling unit owned
		Urban	Saturday	7	20%	1.00	0.90		1.02		1.17		Dwelling Units	
222	High-Rise Apartment	Cent City No	Weekday	7	11%	0.85	1.38		1.37		1.52		Dwelling Units	
224	Rental Townhouse		Weekday	3	5%		1.68		1.73		1.78		Dwelling Units	
230	Condominium/Townhouse	Suburban	Weekday	5	23%	0.90	1.38		1.46		1.68		Dwelling Units	
254	Assisted Living		Weekday	13	17%	0.87	0.33		0.33		0.36		Dwelling Units	0.35/dwelling unit
			Saturday	11	26%	0.82	0.23		0.24		0.30		Dwelling Units	
			Sunday	8	17%	0.85	0.26		0.28		0.34		Dwelling Units	
310	Hotel		Weekday	14	39%	0.75	0.72		0.91		1.14		Rooms	
312	Business Hotel		Weekday	3	14%		0.60		0.64		0.71		Rooms	*1.25/room plus 10.8/100 sq m (10/ksf) GFA for restaurant plus 32.3/100 sq m (30/ksf) GFA for conf/ banquet if 215-540 sq m (20-50 q ft) /room or 21.5/100 sq m (20/ksf) GFA if >540 sq m (50 ksf) /room
			Saturday	3	13%		0.62		0.66		0.72		Rooms	
320	Motel		Weekday	5	15%	0.76	0.83		0.90		1.02		Rooms	
330	Resort Hotel		Weekday	3	45%		1.09		1.42		1.86		Rooms	
430	Golf Course		Saturday	7	17%	0.90	8.38		8.68		9.83		Holes	9.8/hole
437	Bowling Alley	Suburban	Friday	4	14%	0.97	4.58		5.02		5.58		Lanes	5.5/lane
		Suburban	Mon-Thurs	4	20%	0.92	3.88		4.00		4.62		Lanes	
		Urban	Mon-Thurs	3	30%		2.79		3.13		3.78		Lanes	
441	Live Theater	Rural	Weekday	4	3%	0.99	0.38		0.38		0.39		Attendees	*0.4/seat
		Rural	Weekday	4	46%		0.19		0.25		0.32		Seats	
444	Mobie Theater with Matinee		Friday	6	49%	0.65	0.21		0.26		0.36		Seats	
			Saturday	7	25%	0.72	0.20		0.19		0.23		Seats	1 screen: 0.5/seat; 2 to 5 screens: 0.33/seat; 5 to 10 screens: 0.3/seat; over 10 screens*: 0.27/seat
			Sunday	4	45%		0.10		0.11		0.15		Seats	
466	Snow Ski Area	Rural	Saturday	4	27%	0.86	1.02		1.31		1.62		Acres	
		Rural	Saturday	4	30%	0.91	0.20		0.25		0.31		Daily Lift Ticket	
491	Racquet/Tennis Club		Weekday	3	25%		3.05		3.56		4.13		Courts	4/court
492	Health/Fitness Club		Weekday	20	47%	0.61	4.14	(3.85)	5.59	(5.19)	8.90	(8.27)	100 sq m (ksf GFA)	*7.5/100 sq m (7/ksf) GFA
			Weekday	5	44%	0.97	0.10		0.13		0.16		Members	
493	Athletic Club		Weekday	11	41%		2.60	(2.42)	3.82	(3.55)	5.32	(4.94)	100 sq m (ksf GFA)	
			Weekday	7	51%		0.05		0.07		0.12		Members	
495	Recreational Community Center	Suburban	Weekday	5	61%		2.79	(2.59)	4.12	(3.83)	6.26	(5.82)	100 sq m (ksf GFA)	

*The same ratio is recommended in *Shared Parking*, Second Edition

For the evaluation of the project, according to the Handbook, the recommended parking ratio is 1.65 parking space for each dwelling unit rental in the apartment. To calculate the number of rental units, a specific room in each residential unit is marked with the keyword Unit in its property as Figure 38 shows. For the unit with a living room, the living room is selected as the specific room, or one bedroom will be selected as the specific room. Then in the schedule of rooms, the specific rooms marked with the keyword Unit can be filtered and the schedule can calculate the total number of the specific rooms automatically.

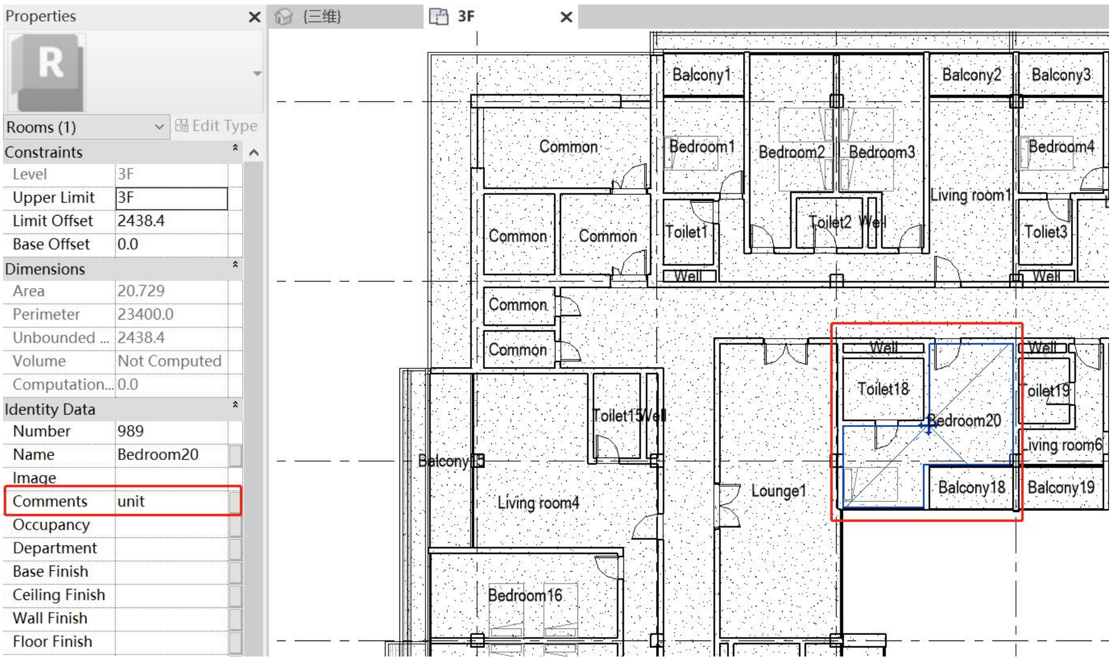


Figure 38. Specific rooms marked with the keyword Unit

The result can be exported into Excel as Table 12 shows. In the Excel, the total number counted in Revit can multiply by 1.65 which is the base ratio and the recommended number for parking spaces is 311.85. With the reduction of 30%, the parking number in the project should less than 218. Since in the existing project, the schedule counts there are only 72 parking spaces which is less than 218, the project can achieve 1 point in this credit.

Table 12

Result for number of dwelling units and parking spaces.

Parking spaces					
Number	Nmae	Level	Area (square meters)	Comments	
1602	Living ro	6F	6.65	unit	
1597	Living ro	6F	6.6	unit	
1624	Living ro	6F	21.78	unit	
1622	Living ro	6F	22.14	unit	
1628	Living ro	6F	28.24	unit	
2058	Bedroom7	7F	20.4	unit	
2069	Living ro	7F	27.15	unit	
2054	Living ro	7F	42.44	unit	
2049	Living ro	7F	6.65	unit	
1986	Living ro	7F	6.65	unit	
1987	Living ro	7F	6.65	unit	
1982	Living ro	7F	6.68	unit	
2004	Living ro	7F	21.78	unit	
2002	Living ro	7F	22.14	unit	
2008	Living ro	7F	27.51	unit	
2109	Living ro	8F	27.15	unit	
2103	Living ro	8F	42.44	unit	
2133	Living ro	9F	27.15	unit	
2129	Living ro	9F	42.44	unit	
189					311.85
					218.295
					72

6.2.6 LT Credits: Electric Vehicles

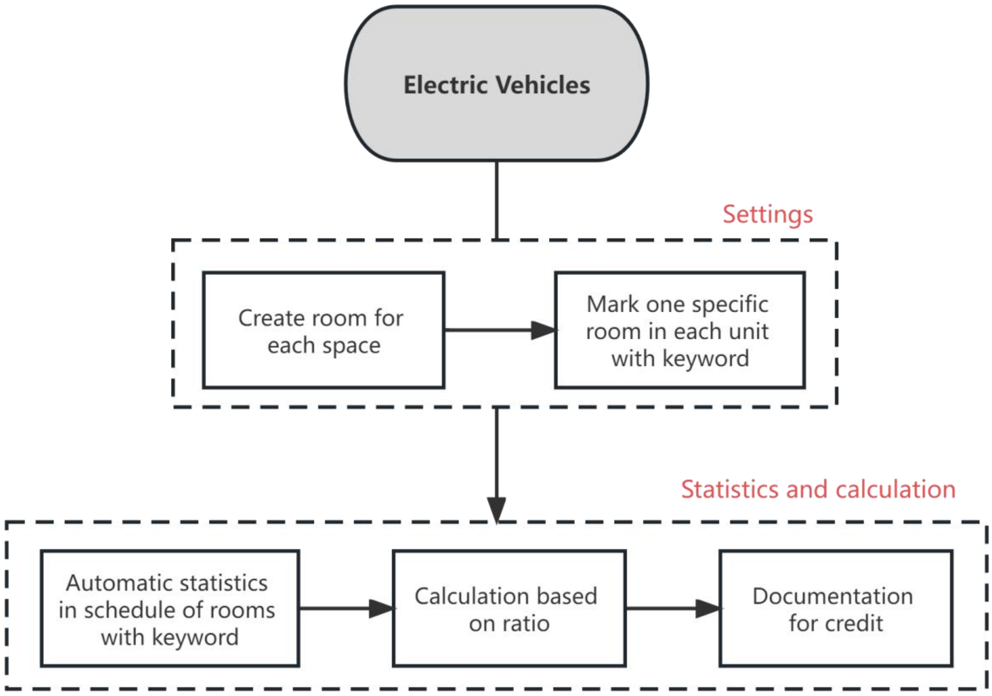


Figure 39. Workflow for the credit

The intent of the credit is to reduce pollution by promoting alternatives to conventionally fueled automobiles.
The credit rewards the project which installs electrical vehicle supply equipment (EVSE) in 2% of all parking spaces used by the project or at least two spaces, whichever is greater. Since there are 72 parking spaces in total, two parking spaces need to install electrical vehicle supply equipment to achieve the point. So in Revit, two parking spaces are marked specially as equipped with electrical vehicle supply equipment in their properties as Figure 40 shows.

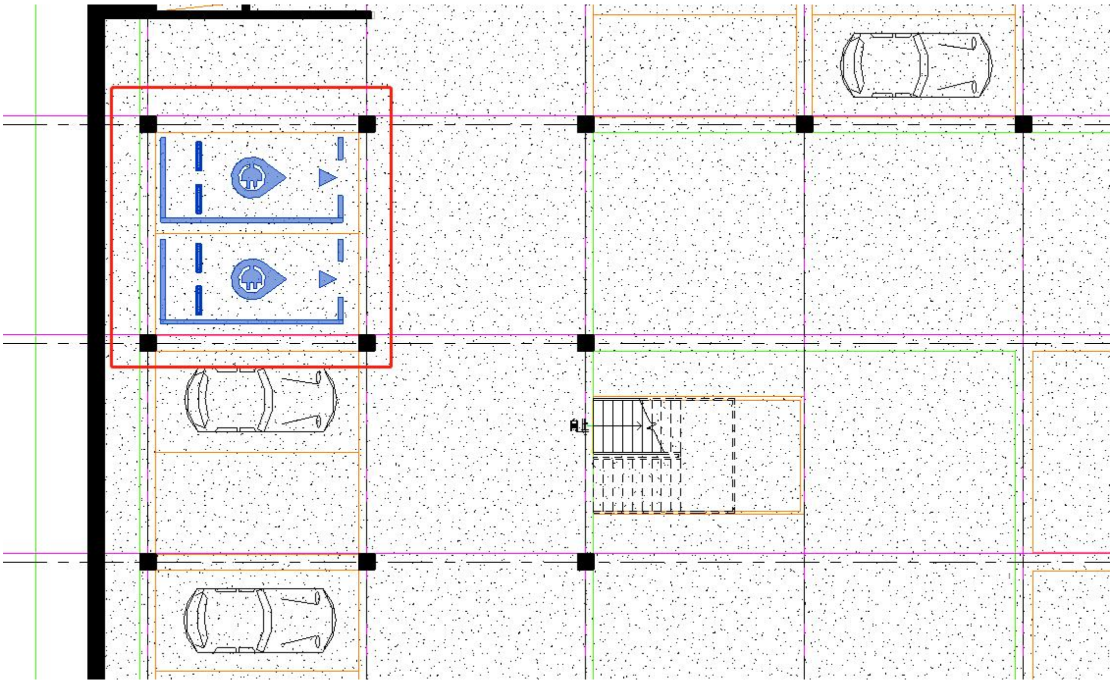


Figure 40. Parking spaces with electrical vehicle supply equipment

6.2.7 LT Credits: Open Space

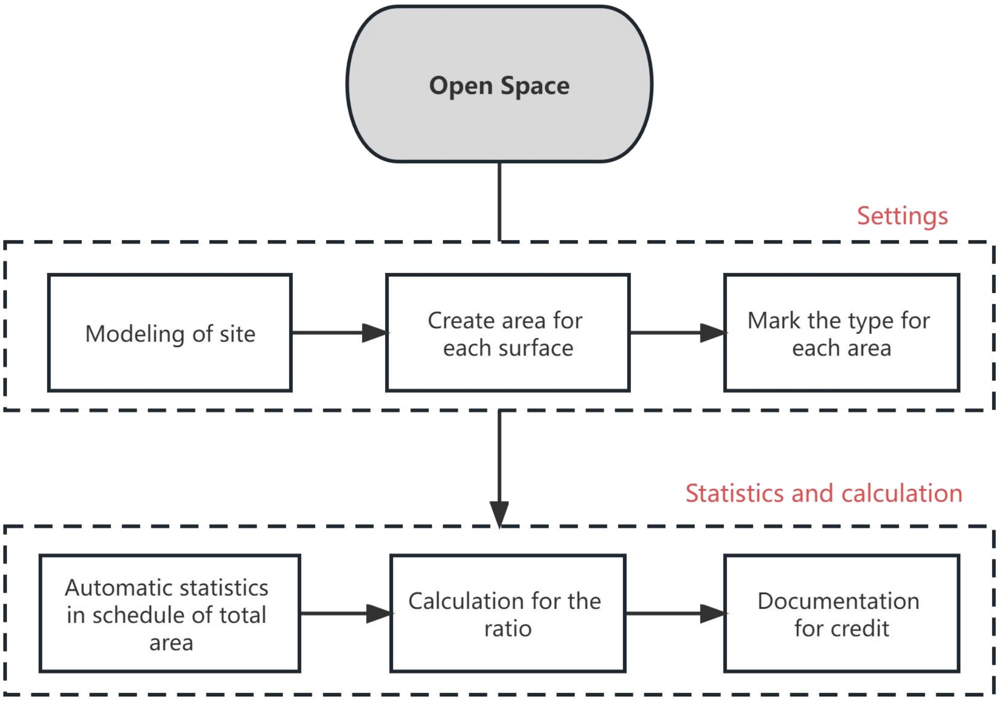


Figure 41. Workflow for the credit

The intent of the credit is to create exterior open space that encourages interaction with the environment, social interaction, passive recreation, and physical activities.
The credit rewards the project which provides outdoor space greater than or equal to 30% of the total site area. In addition, 25% of the minimum 30% total outdoor space requirement must be planted with two or more types of vegetation or have overhead vegetated canopy. The outdoor space must be physically accessible and a pedestrian or recreation oriented paving or landscape area that accommodate outdoor social activities.
The design of the site plan of the project is shown in Figure 42 with different kinds of greenery and pavement. For the evaluation of the project, based on the site model, first the area of the whole site is identified and calculated by the Area panel of Revit. Then the site plan is divided into several parts like building, road, pavement and vegetation as Figure 44 shows and each part is also marked and calculated in the panel of Area. Since some of the roof areas are vegetated roof which can also be counted as the open space, each vegetated roof on different floors is also marked as Figure 45 shows and calculated in the panel of Area. Finally, in the schedule of total area, the total area of different spaces can be counted automatically.

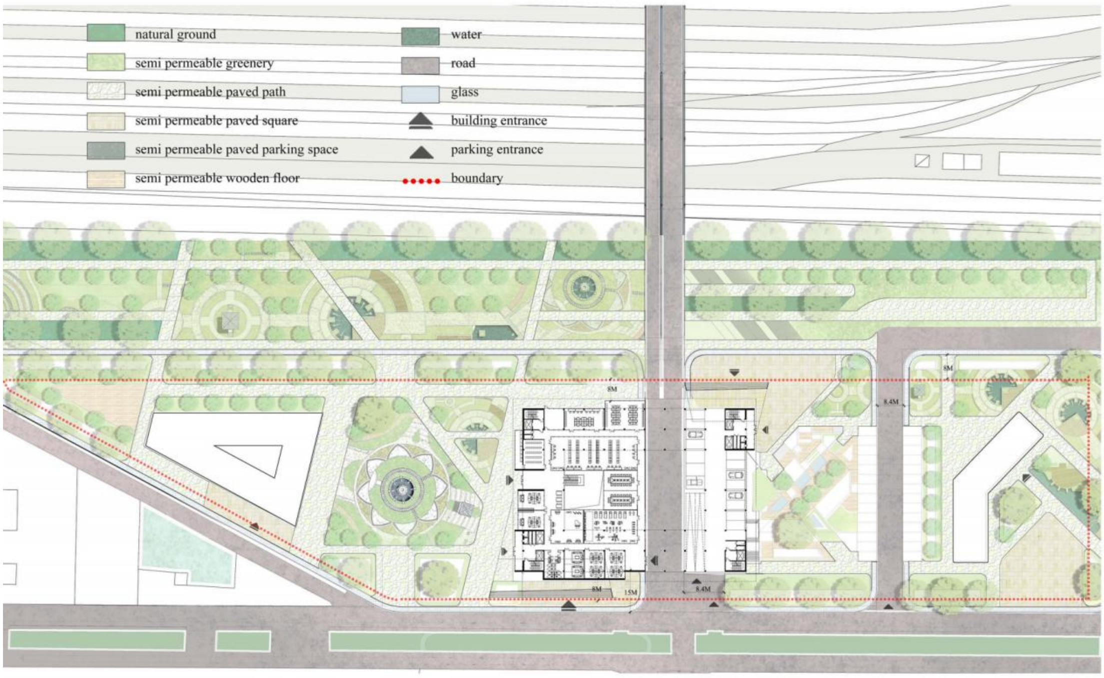


Figure 42. Site plan of the project

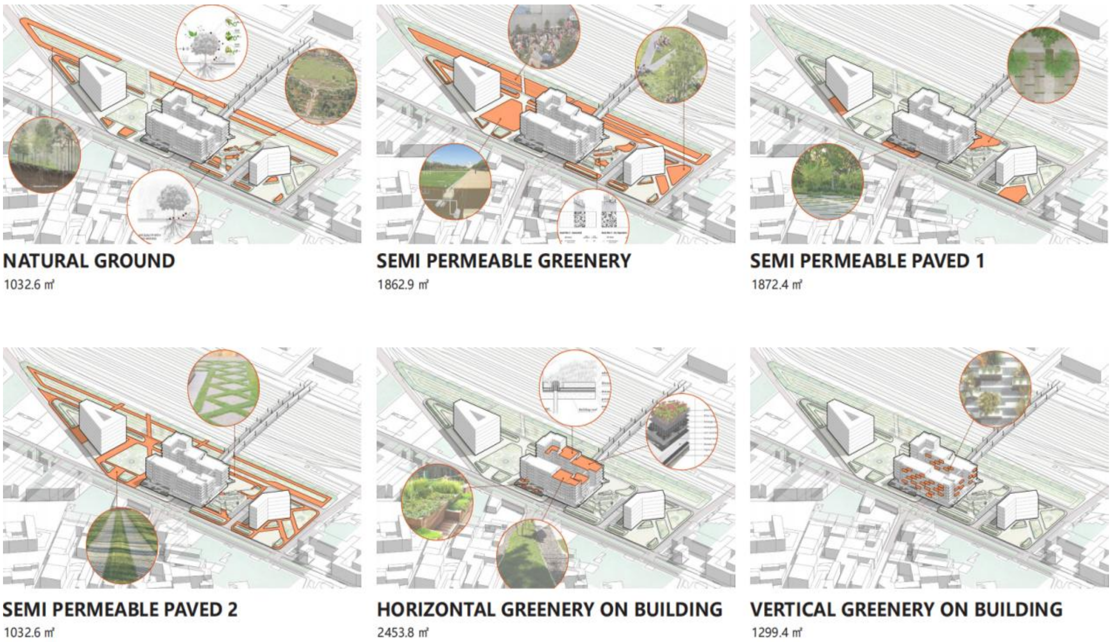


Figure 43. Green solution of the project

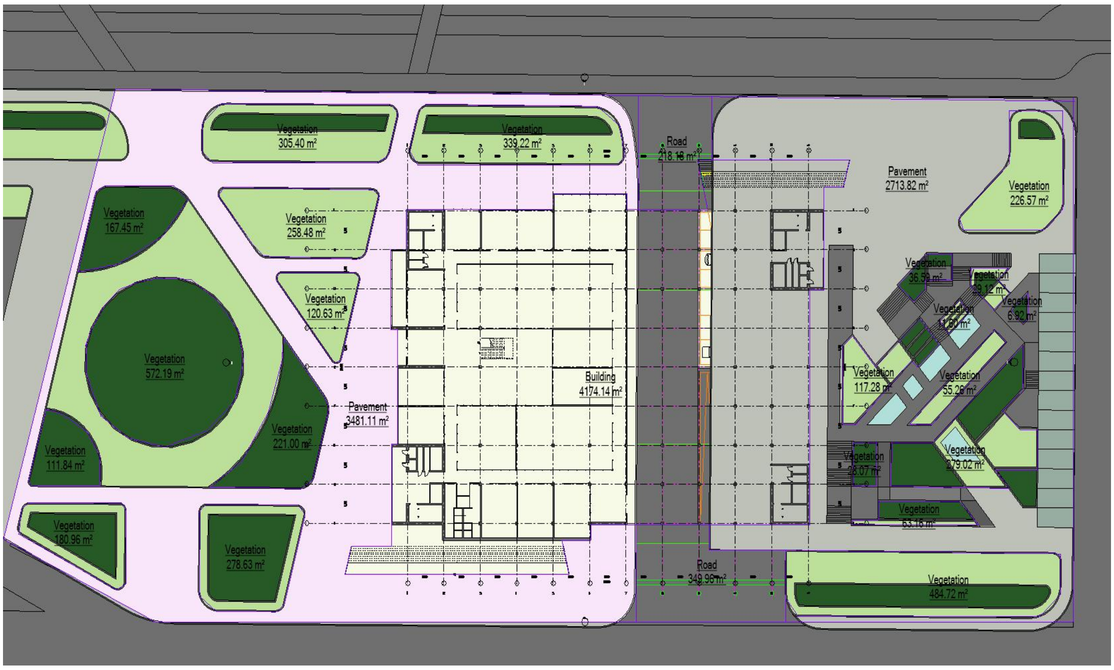


Figure 44. Different types of vegetation and pavement

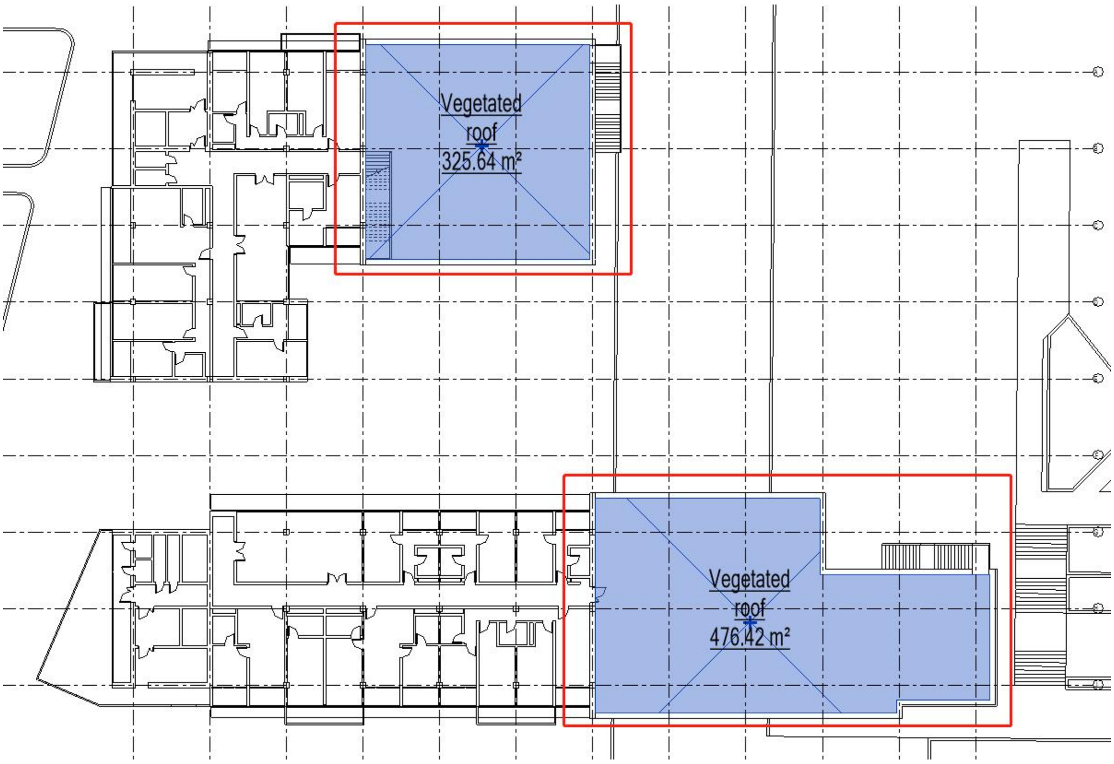


Figure 45. Vegetated roofs

The result can be exported into Excel as Table 13 shows. In the Excel, the total area of open space can be calculated as Open Space Area = Site Area - Building Floor Area - Road Area + Vegetated Roof Area and the final result is 12467 square meters. So the percentage of the open space is Open Space Area / Site Area = 85.02%, which is over 30%. For the total area of open space with vegetation, it is can be calculated as Open Space with Vegetation Area = Vegetated Roof Area + Vegetation Area and the final result is 6440 square meters. So the percentage of the open space with vegetation is Open Space with Vegetation Area / Open Space Area = 51.66%, which is over 25%. As a result, the project can achieve 1 point in this credit.

Table 13
Result for area of site, open spaces and vegetation.

Name	Level	Area(m2)	Total		Percentage%
Site	0F	14663	2		
Building	0F	4174	1		
Road	0F	568	2		
Pavement	0F	6195	2		
High-reflectance roof	multi	1090	2		
Vegetated roof	multi	2546	6		
Vegetation	0F	3894	21		
Open space		12467			85.02352861
Open space with vegetation		6440			51.65637282

6.2.8 SS Credits: Heat Island Reduction

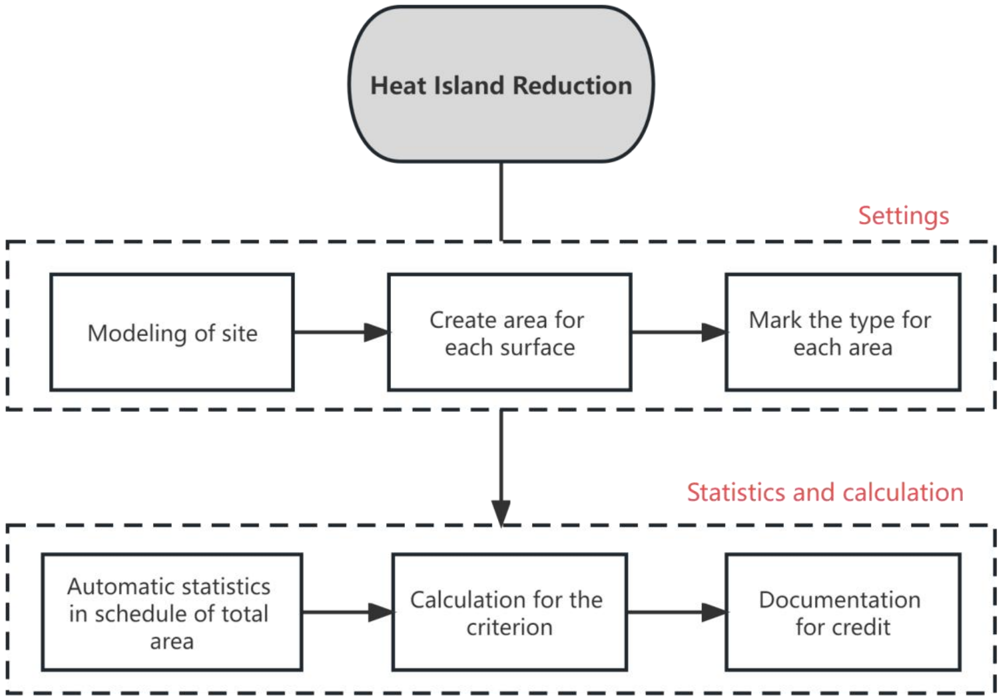


Figure 46. Workflow for the credit

The intent of the credit is to minimize effects on microclimates and human and wildlife habitats by reducing heat islands.
The credit rewards the project which meets the following criterion:

$$\frac{\text{Area of Nonroof Measures}}{0.5} + \frac{\text{Area of High-Reflectance Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.75} \geq \text{Total Site Paving Area} + \text{Total Roof Area}$$

The nonroof measure means nonroof area which can provide shade with plants, vegetated structures or energy generation systems, or the area which uses an open-grid pavement system (at least 50% unbound).
As the site plan shows, the path, square and parking spaces are semi permeable, so they can be counted as the nonroof measure. As Figure 47 shows, the roofs without vegetation but with high-reflectance are counted as high-reflectance roof, and each high-reflectance roof is marked and calculated in the panel of Area. Finally, in the schedule of total area, the total area of different kinds of roofs can be counted.

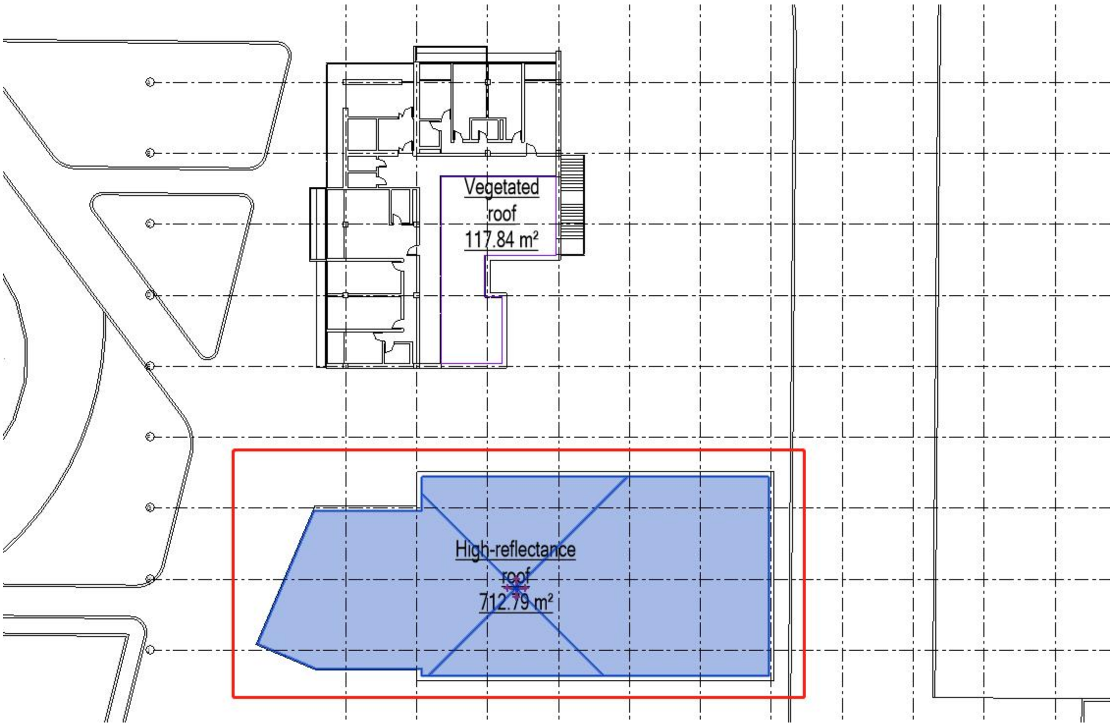


Figure 47. High-reflectance roofs

In Table 14, the area of nonroof measures can be calculated as Area of Nonroof Measures = Site Area - Building Floor Area - Road Area and the final result is 9921 square meters. And as the statistics result of the schedule of total area in Revit, the area of high-reflectance roof is 1090 square meters, the area of vegetated roof is 2546 square meters, the total site paving area is 6195 square meters and the total roof area is 3636 square meters. The left criterion is 24690 square meters and the right criterion is 9831 square meters. The left criterion is larger than the right criterion, so the project can achieve 2 points in this credit.

Table 14

Result for area of nonroof measures, high-reflectance roof and vegetated roof.

Name	Level	Area(m2)	Total		Percentage%
Site	0F	14663	2		
Building	0F	4174	1		
Road	0F	568	2		
Pavement	0F	6195	2		
High-reflectance roof	multi	1090	2		
Vegetated roof	multi	2546	6		
Vegetation	0F	3894	21		
Open space		12467			85.02352861
Open space with vegetation		6440			51.65637282
Total roof area		3636			
Nonroof measures		9921			
Left criterion		24690			
Right criterion		9831			Left>Right

6.2.9 EQ Credits: Quality Views

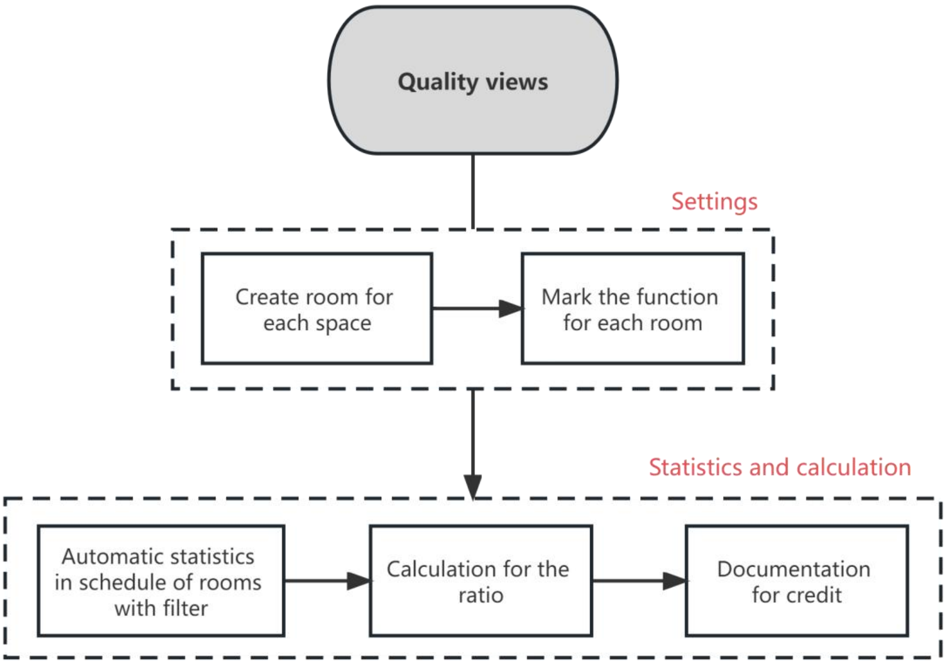


Figure 48. Workflow for the credit

The intent of the credit is to give building occupants a connection to the natural outdoor environment by providing quality views.

The credit rewards the project which achieves a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area. The views need to include sky and movement, and located within the distance of three times the head height of the vision glazing.

For the evaluation of the project, the panel of Room is used to identify different rooms separated by walls and marked as lounge, office, bedroom, balcony, kitchen and toilet according to their uses as Figure 49 shows. The schedule of rooms can show the name, floor and area of each room. The schedule is created twice, the first time it includes all regularly occupied rooms and the second time it only includes the keyword lounge, office, balcony, bedroom and living room which can achieve sight to the outdoors.

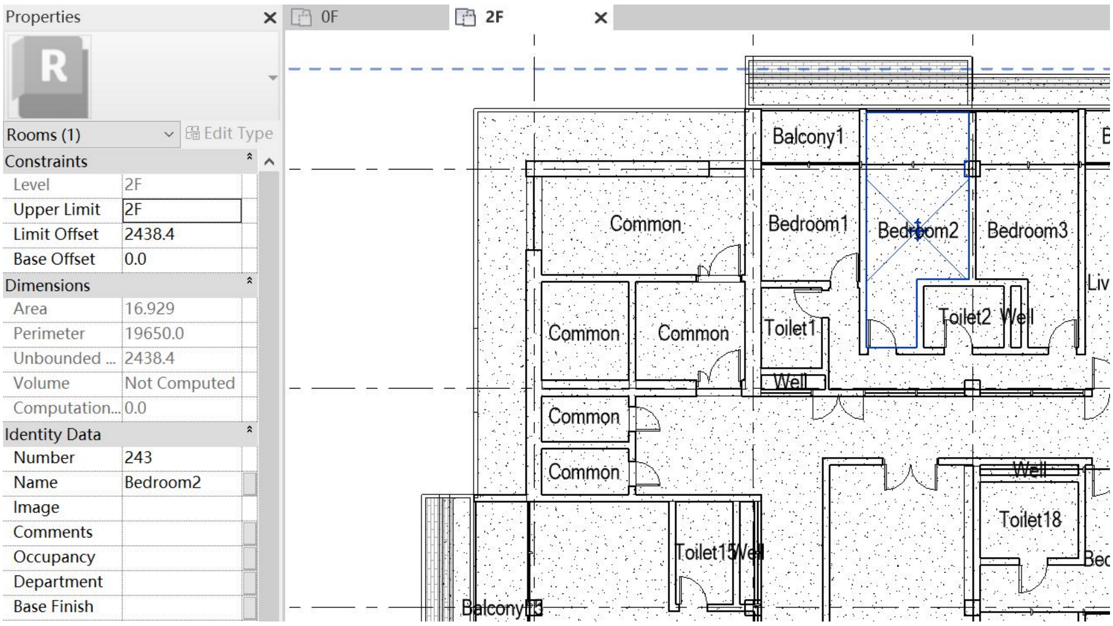


Figure 49. Rooms marked according to their uses

The result can be exported into Excel for further calculation as Table 15 shows. And through the excel, the total area of all regularly occupied rooms is 10844 square meters and the total area of rooms with sight is 8945 square meters. The percentage of the areas with sight is 82.49% which is larger than 75%, so the project can achieve 1 point in this credit.

Table 15

Result for area of all the rooms and rooms with direct sight.

Quality views								
Number	Name	Level	Area(square meters)		Number	Name	Level	Area(square meters)
2123	Balcony1	9F	4.1		2123	Balcony1	9F	4.1
2122	Balcony2	9F	4.1		2122	Balcony2	9F	4.1
2124	Balcony3	9F	8.84		2124	Balcony3	9F	8.84
2125	Balcony4	9F	4.1		2125	Balcony4	9F	4.1
2114	Bedroom1	9F	9.46		2114	Bedroom1	9F	9.46
2132	Bedroom2	9F	16.93		2132	Bedroom2	9F	16.93
2131	Bedroom3	9F	16.93		2131	Bedroom3	9F	16.93
2126	Bedroom4	9F	19.27		2126	Bedroom4	9F	19.27
2127	Bedroom5	9F	19.27		2127	Bedroom5	9F	19.27
2130	Bedroom6	9F	9.46		2130	Bedroom6	9F	9.46
2133	Living roo	9F	27.15		2133	Living room1	9F	27.15
2129	Living roo	9F	42.44		2129	Living room2	9F	42.44
2110	Toilet1	9F	4.03					
2112	Toilet2	9F	4.03					
2113	Toilet3	9F	4.87					
2116	Toilet4	9F	4.03					
			10844.46					8945.22
								0.824865415

6.2.10 WE Prerequisite: Indoor Water Use Reduction

The intent of the prerequisite is to reduce indoor water consumption. The prerequisite needs the project to reduce aggregate water consumption by 20% from the baseline. Base calculations on the volumes and flow rates for the fixtures and fittings are shown in Table 17 in the next chapter. In addition, all newly installed toilets, urinals, private lavatory faucets, and showerheads that are eligible for labeling must be WaterSense labeled. The detailed method for choosing the labeled fixtures will also be discussed in the next chapter.
The project satisfies the requirements of the prerequisite and the detailed operations for verification will be displayed below.

6.2.11 WE Credit: Indoor Water Use Reduction

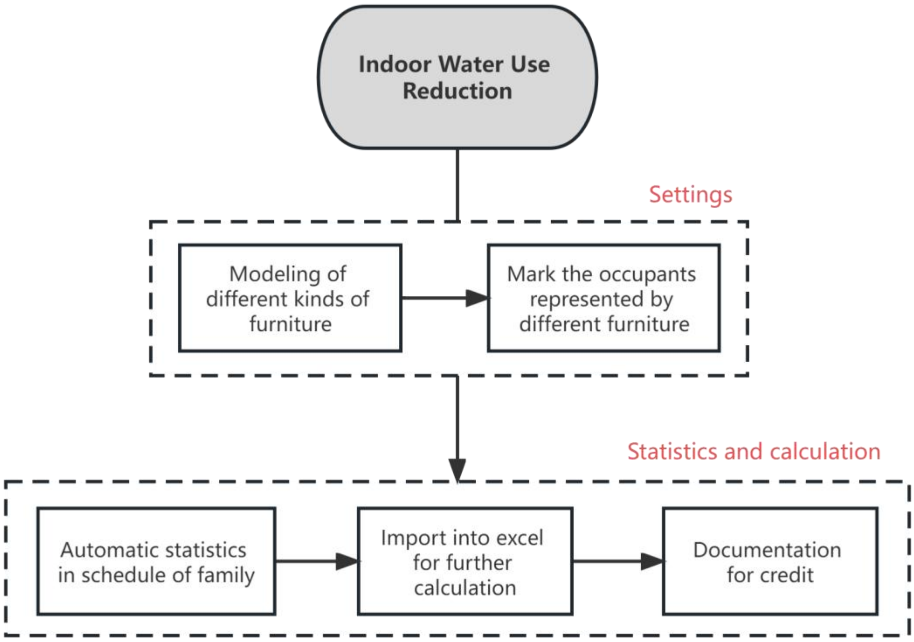


Figure 50. Workflow for the credit

The intent of the credit is to reduce indoor water consumption. The credit rewards the project which can further reduce fixture and fitting water use from the calculated baseline in WE Prerequisite Indoor Water Use Reduction. Points are awarded according to Table 16.

Table 16

Points for reducing water use.

Percentage Reduction	Points (BD+C)	Points (CS)	Points (Schools, Retail, Hospitality, Healthcare)
25%	1	1	1
30%	2	2	2
35%	3	3	3
40%	4	4	4
45%	5	--	5
50%	6	--	--

For the evaluation of the project, the calculation of the reduction is based on the Indoor Water Use Reduction Calculator. And the assumption of the baseline water use of different kinds of fixtures and occupancy is shown in Table 17. First, to calculate the number of different kinds of occupancy, different components from the libraries of the Revit are set into the model to represent different kinds of occupancy. The bed component is used to calculate the number of residents, the office desk component is used to calculate the number of employees and the chair component is used to calculate the capacity for visitors. Then the representative group of the components are marked inside the property of each component. In the schedule of the family of components, the number of each kind of component is counted. The number of each kind of occupancy can be inserted into Table 18 and the default gender ratio is 50% to 50%.

Table 17

Assumption of the baseline water use of different kinds of fixtures and occupancy.

Fixture Type	Maximum Installed Flush/Flow Rate		Duration (sec)
	IP	SI	
Toilet (male)	1.60 gpf	6.00 lpf	n/a
Toilet (female)	1.60 gpf	6.00 lpf	n/a
Urinal	1.00 gpf	3.80 lpf	n/a
Public lavatory (restroom) faucet	0.50 gpm	1.90 lpm	30
Private (residential) lavatory faucet	2.20 gpm	8.30 lpm	60
Kitchen faucet	2.20 gpm	8.30 lpm	15
Residential kitchen faucet	2.20 gpm	8.30 lpm	60
Showerhead	2.50 gpm	9.50 lpm	300
Residential showerhead	2.50 gpm	9.50 lpm	480

Fixture Type	Default Uses per Day				
	Employees (FTE)	Visitors	Retail Customers	Students (K-12)	Residential
Toilet (male)	1	0.1	0.1	1	5
Toilet (female)	3	0.5	0.2	3	5
Urinal	2	0.4	0.1	2	0
Public lavatory (restroom) faucet	3	0.5	0.2	3	0
Private (residential) lavatory faucet	0	0	0	0	5
Kitchen faucet	1	0	0	0	0
Residential kitchen faucet	0	0	0	0	4
Showerhead	0.1	0	0	0	0
Residential showerhead	0	0	0	0	1

Table 18

Result for number of occupancy and gender ratio.

Occupancy Type	Employees (FTE)	Visitors	Retail Customers	Students (K-12)	Residential	Other *(specify)*	Gender Ratio (%)
Total	18	328	0	0	399	0	100%
Male	9	164	0	0	200	0	50%
Female	9	164	0	0	199	0	50%

The next step is to look for the design flush rate for each kind of fixture which meets the requirement of the Water Label. The design flush rate of them which is available in Italy can be found on website http://www.europeanwaterlabel.eu/findaproduct.asp, like Figure 51 shows. The parameters of each kind of fixture are also built and set in the Revit model as Figure 52, 53 shows. The design flush rate can be inserted into the table and the percent of occupants is 100%. And based on the uses per day of different kinds of occupants, the baseline case annual flush volume and the design case annual flush volume can be calculated automatically as Table 19 shows. In summary, the percentage of water use reduction is 43.57% which means the project can achieve 4 points in this credit.

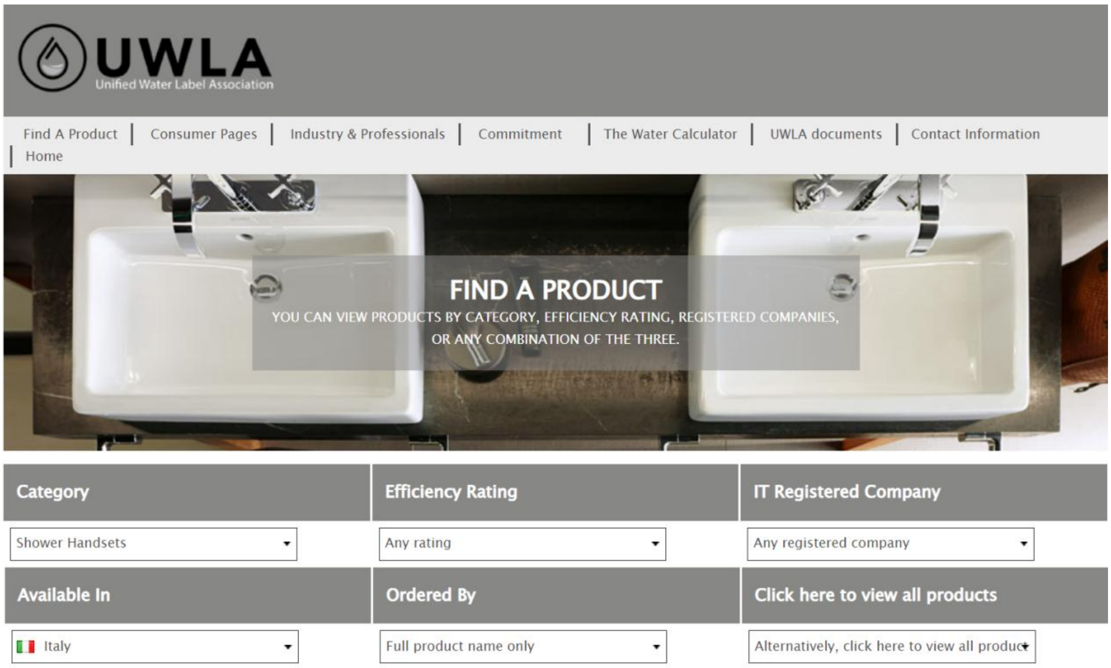


Figure 51. Website to find efficiency fixtures

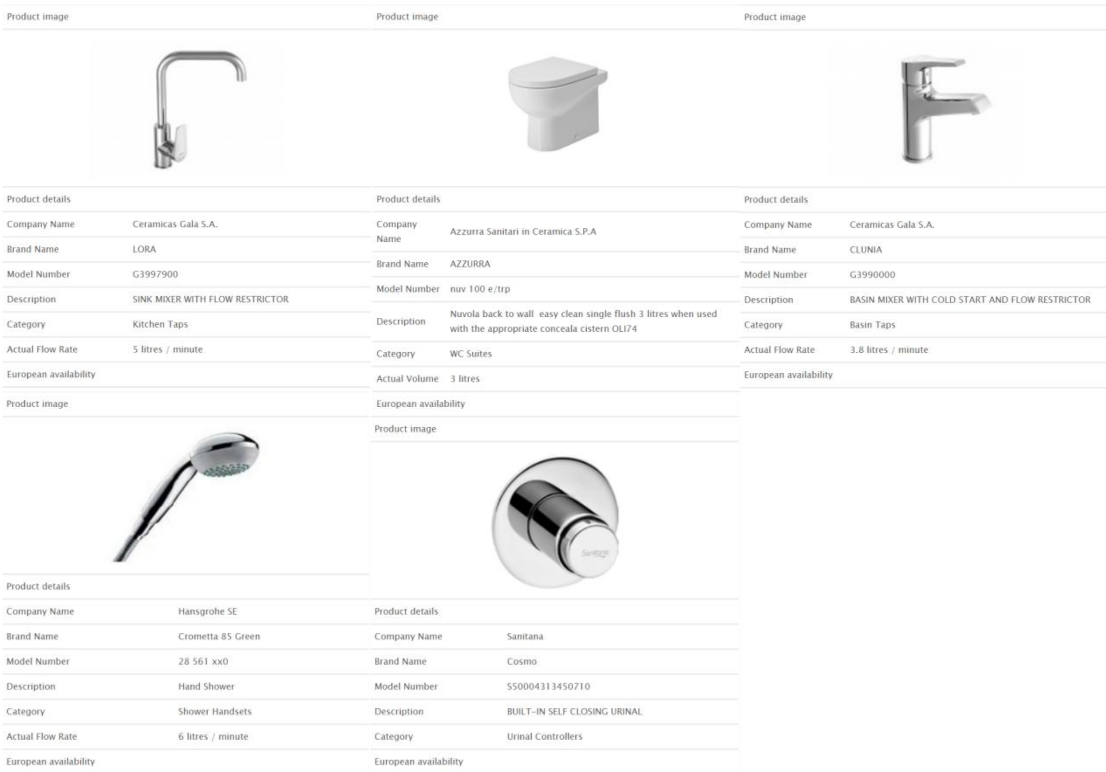


Figure 52. Fixtures chosen for the project

Figure 53. Modeling and set for each kind of fixture

Table 19

Calculation for baseline and design annual flow volumes.

Fixture Information			Flush Rate		Percent of Occupants (%)
Fixture ID	Fixture Family	Fixture Type	Baseline Flush Rate (lpf)	Design Flush Rate (lpf)	
1	Toilet (male)		6.00	3	100
2	Toilet (female)		6.00	3	100
3	Urinal		3.80	1.9	100
Baseline case annual flush volume (liters/year)					4,779,339.20
Design case annual flush volume (liters/year)					2,389,669.60

Fixture Information		Duration		Flow Rate		Percent of Occupants (%)
Fixture ID	Fixture Type	Default (sec)	Non-default (sec) (Optional)	Baseline Flow Rate (lpm)	Design Flow Rate (lpm)	
4	Public lavatory (restroom) faucet	30		1.90	1.6	100
5	Private (residential) lavatory faucet	60		8.30	3.8	100
6	Residential kitchen faucet	60		8.30	5	100
7	Residential showerhead	480		9.50	6	100
Baseline case annual flow volume (liters/year)						22,022,786.00
Design case annual flow volume (liters/year)						12,733,901.00

Table 20

Summary for indoor water use reduction.

Group Name	Baseline Case (liters/year)			Design Case (liters/year)		
	Annual Flush Volume	Annual Flow Volume	Annual Consumption	Annual Flush Volume	Annual Flow Volume	Annual Consumption
Group 1	4,779,339.20	22,022,786.00	26,802,125.20	2,389,669.60	12,733,901.00	15,123,570.60

Annual baseline water consumption (liters/year)	26,802,125.20
Annual design water consumption (liters/year)	15,123,570.60
Percent water use reduction (%)	**43.57%**

In summary, through the assessment with the BIM-based statistics and calculation, 23 points in 9 credits from 4 categories can be evaluated and the project can achieve 21 points in total as Table 21 shows.

Table 21

Summary for the assessment with BIM-based statistics and calculation.

Category	Credit	Available points	Earned points
Prerequisite	Indoor Water Use Reduction	Required	Required
Location and Transportation	Surrounding Density and Diverse Uses	5	5
Location and Transportation	Access to Quality Transit	5	5
Location and Transportation	Bicycle Facilities	1	1
Location and Transportation	Reduced Parking Footprint	1	1
Location and Transportation	Electric Vehicles	1	1
Sustainable Sites	Open Space	1	1
Sustainable Sites	Heat Island Reduction	2	2
Water Efficiency	Indoor Water Use Reduction	6	4
Indoor Environmental Quality	Quality Views	1	1
Assessment with BIM-based statistics and calculation		23	21

6.3 Assessing through BIM-based Performance Simulation

6.3.1 Interface of BIM Software with Other Green Building Analysis Software

For a long time, various design analysis software in the construction industry have adopted different programs, resulting in a lack of interoperability between programs, which greatly reduces the efficiency of users. At present, the more common data formats of green building performance simulation software include IFC, gbXML, dxf and other types, among which IFC format and gbXML format are BIM file formats that can describe building geometric information, material parameters, building attributes and other information. The Dxf format is a vector data format, which only describes the graphic information drawn in CAD, and is often used for data exchange between different CAD software.

The IFC data format was created by Building Smart Company, the main purpose is to improve the interoperability of various professional applications, and develop a neutral and open data storage format. The IFC data format is usually neutral and not controlled by other companies or institutions. The IFC data format is expressed by objects, mainly including collection data of buildings. For example, the description of main components such as beams, slabs, columns, stairs, and glass curtain walls of the building also includes the spatial coordinates of the building, the cost of various building materials, the engineering quantity of the building, and the construction budget. The advantage of IFC data is that it can not only describe the construction process, equipment installation and commissioning process in detail, but also describe the more abstract structure calculation process, energy consumption calculation process, bill of quantities, etc., which is also a common data format in BIM.

The data format of the gbXML standard is a data format announced by Bentley in 2000, which aims to provide a better information interface between the building information model and the green building design software. Currently common BIM software such as Revit, Archicad and green building design software such as GBS, Ecotect, IESVE, etc. all support files in gbXML format. The goal of green building data exchange is to realize the sharing of data related to green buildings in different design software and analysis software. Since the purpose of gbXML format development is to solve the interoperability problem of building energy models in different software, the information contained is all information related to building energy conservation and energy consumption. The IFC model is highly versatile and can contain information about the entire life cycle of a building, resulting in more redundant information in the IFC file, so gbXML is more targeted than the IFC format standard in supporting green building design.

6.3.2 Overview of Main Building Performance Simulation and Analysis Software

As the promotion of BIM technology, most of the building performance analysis software is actively connecting with BIM technology, and the relevant building performance and energy consumption analysis is carried out through the building model established on the BIM platform. The promotion of BIM technology has improved the efficiency of traditional green building performance and energy consumption simulation work, and lowered the threshold for simulation analysis, making more and more designers willing to use green building performance and energy consumption simulation analysis tools to optimize the design from the perspective of green buildings. This section mainly introduces four green building performance simulation software with friendly operation interface and widely used in the design industry: "Termolog", "Insight", "IES(VE)" and "One click LCA".

Termolog is the BIM software to calculate the energy efficiency of buildings under Lombardy Regional Regulations. It helps architects design sustainable buildings and reduce consumption and emissions from initial analysis. It can analyze possible scenarios and assess comfort, future fuel consumption, CO_2 emissions and how to compensate for them. It can also be used for Ecobonus, Superbonus, ENEA practices, nZEB and energy audits. Besides IFC, gbXML and dwg files for geometric properties, all types of files (XML, PDF, images, documents) can be imported from other software (Figure 54).

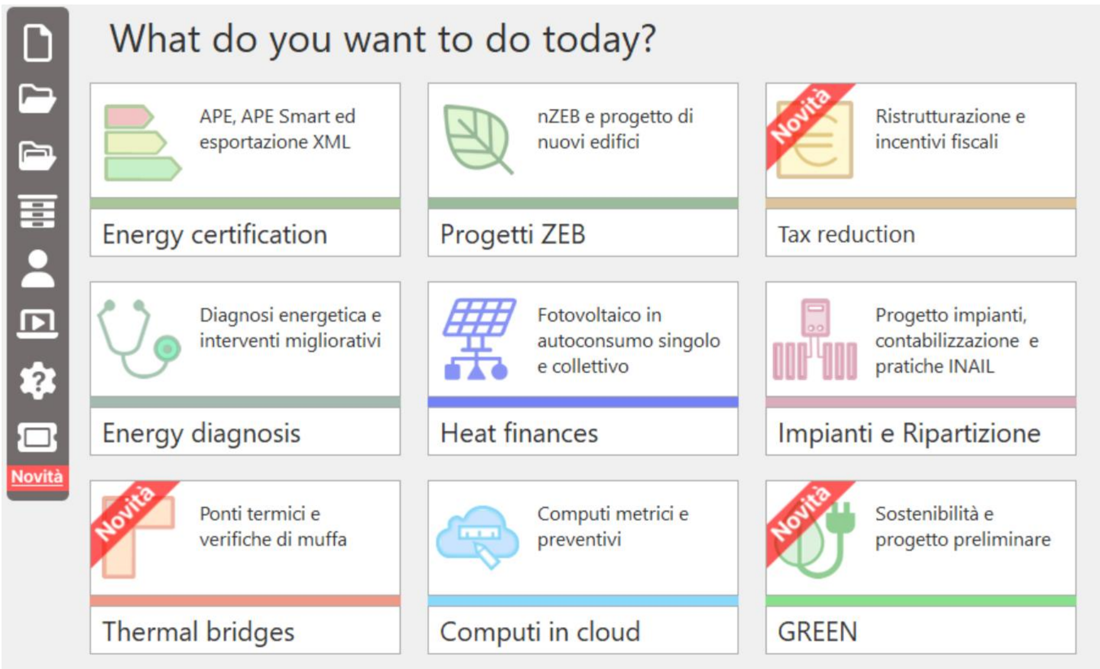


Figure 54. Energy certification and diagnosis with Termolog

Insight is a plug-in inside Revit, which is a cloud-based analysis tool helps to improve energy and environmental performance through the building life cycle by integrating energy, lighting and solar analysis. It can empower architects and engineers to design energy-efficient buildings with simulation engines and building performance analysis data integrated in Revit. In addition, it can visualize and interact with key performance, indicator factor ranges and specifications with real-time cause and effect feedback (Figure 55).

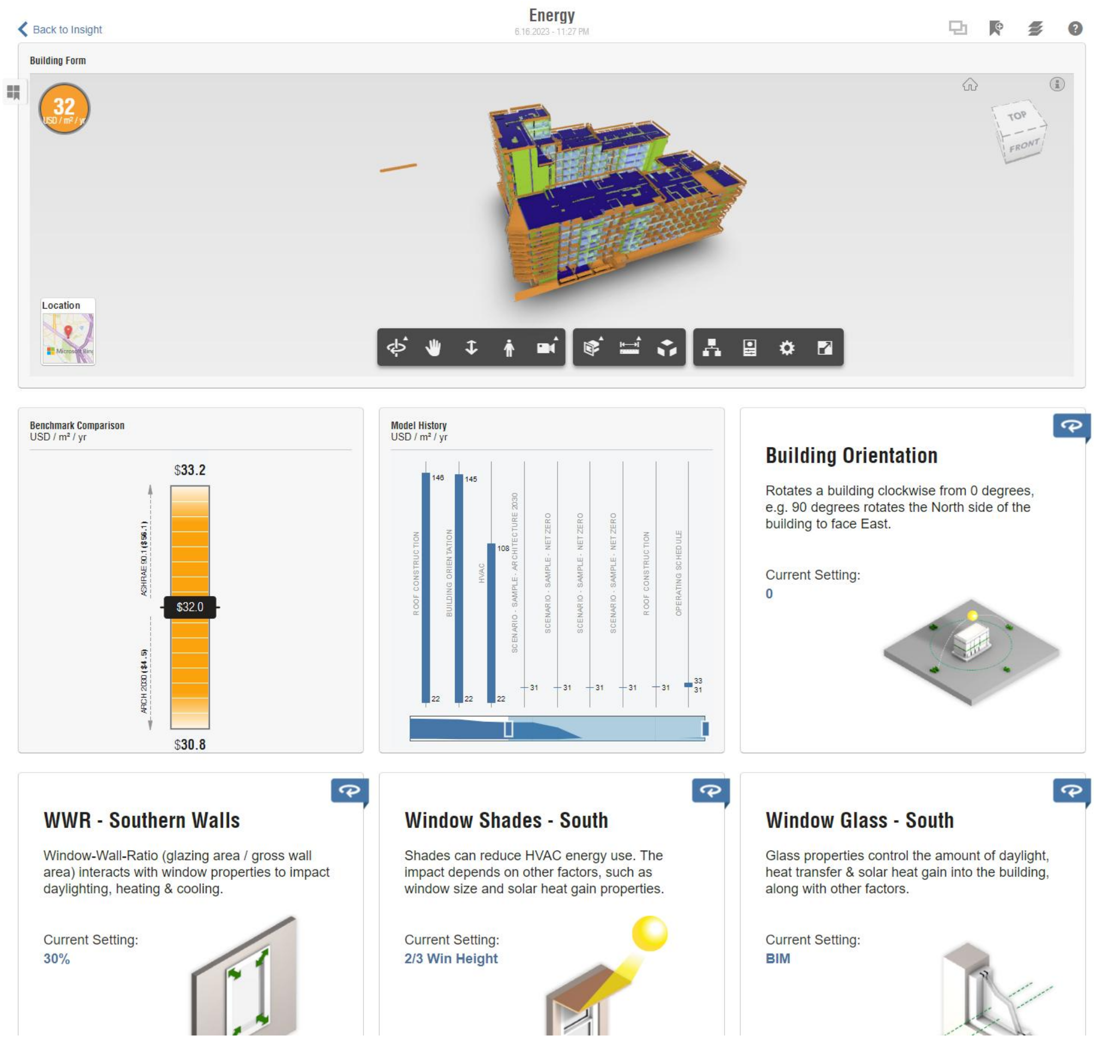


Figure 55. Visualization and interaction of Insight Revit

The IES Virtual Environment (VE) is a suite of building performance analysis applications which is developed by Integrated Environmental Solutions Ltd. It can be used by designers to test different options, identify passive solutions, compare low-carbon & renewable technologies, and draw conclusions on energy use, CO2 emissions and occupant comfort. The VE contains an integrated central data model, which has direct links to SketchUp, Revit, Vectorworks and gbXML, IFC & dxf imports. The following framework (Fig. 56) was adopted to export the model into IES-VE software to run various analyses and produce necessary documents.

Figure 56. Key steps involved in sustainability analyses

One Click LCA (Figure 57) can connect to Autodesk Revit, Rhino, Grasshopper, Autodesk Platform Services, IES-VE, DesignBuilder and 10 other design and BIM software tools to automate the life-cycle assessments. The platform includes all the world's EPD data, a broad range of governmental and industry databases as well as an extensive library of generic data for modelling MEP systems and other elements for which public environmental data is in very scarce supply. It can compare design options, optimise carbon, cost, circularity throughout the design process, and achieve credits from LEED®, BREEAM, and 40+ Green Building Certifications.

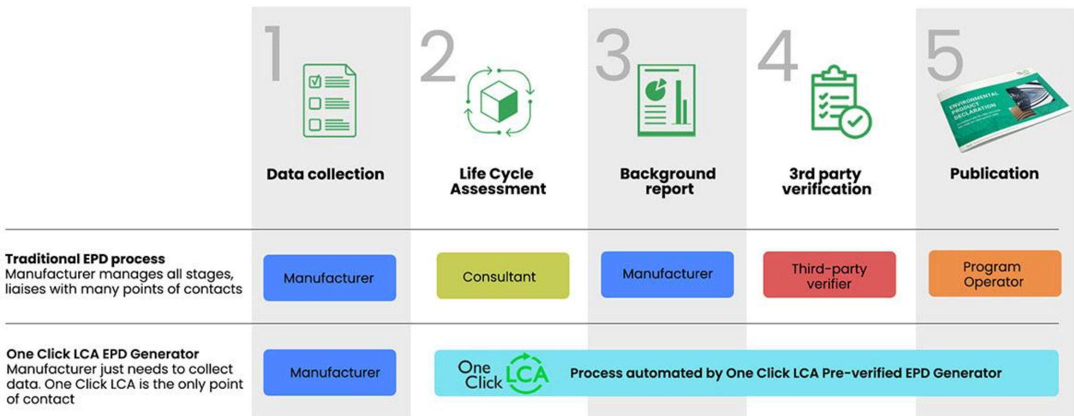


Figure 57. Comparison between One Click LCA and traditional EPD process

6.3.3 EQ Credit: Daylight

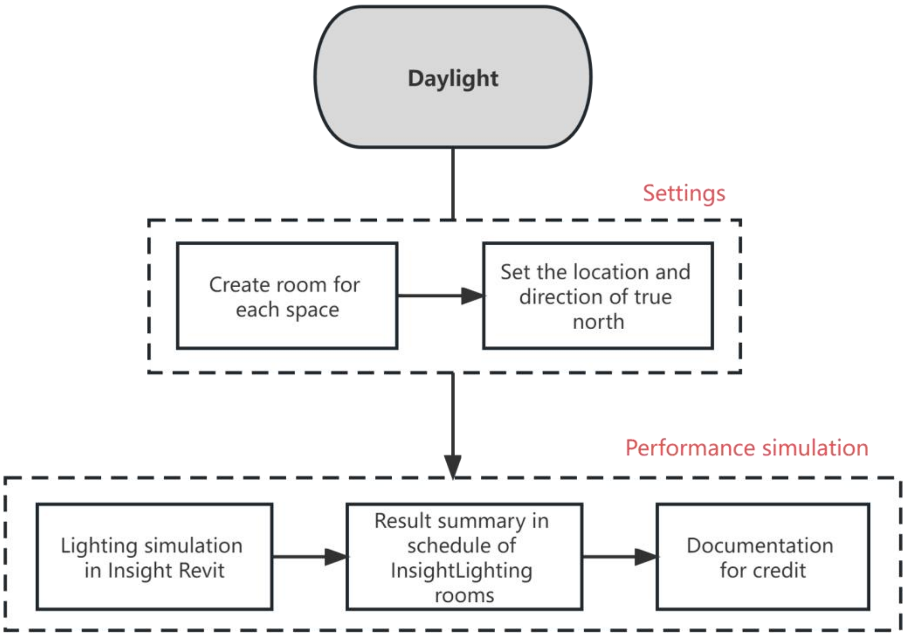


Figure 58. Workflow for the credit

The intent of the credit is to connect building occupants with the outdoors, reinforce circadian rhythms, and reduce the use of electrical lighting by introducing daylight into the space.
The credit rewards the project which provides manual or automatic (with manual override) glare-control devices for all regularly occupied spaces. The project needs to perform annual computer simulations for spatial daylight autonomy$_{300/50\%}$ (sDA$_{300/50\%}$), and annual sunlight exposure$_{1000,250}$ (ASE$_{1000,250}$) as defined in IES LM-83-12 for each regularly occupied space. Points are awarded according to Table 22.

Table 22

Points for simulation of spatial daylight autonomy and annual sunlight exposure.

	New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality	Healthcare
The average sDA$_{300/50\%}$ value for the regularly occupied floor area is at least **40%**	1 point	1 point
The average sDA$_{300/50\%}$ value for the regularly occupied floor area is at least **55%**	2 points	2 points
The average sDA$_{300/50\%}$ value for the regularly occupied floor area is at least **75%**	3 points	Exemplary performance

For the evaluation of the project, the software Insight is used for building daylight performance simulation. Insight is a plug-in inside Revit, which is a cloud-based analysis tool helps to improve environmental performance through the building life cycle. For the simulation, the first step is to place rooms for each area of the building in the plan with the panel Room which is defined by the walls. Then the location of the project and the direction of true north needs to be set as Figure 60 shows. The rooms placed before except wells and corridors can be simulated with lighting analysis and the detailed parameters are set as Figure 61 shows. The date range is from January 1 to December 31, and the time range is from 8 a.m. to 6 p.m.

Figure 59. The flow of how Insight Revit works

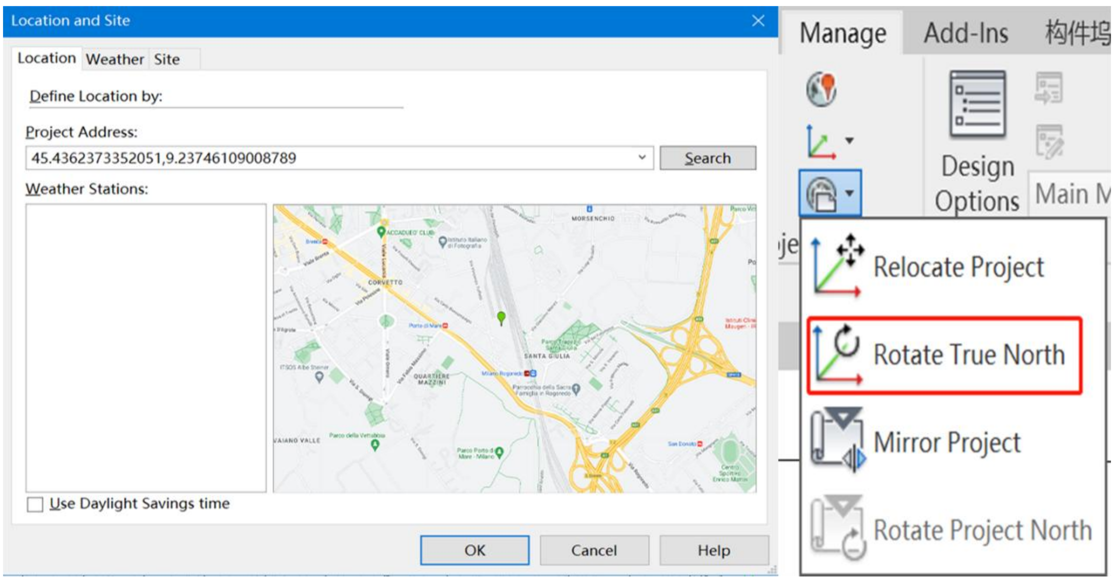


Figure 60. The set of location and true north of the site

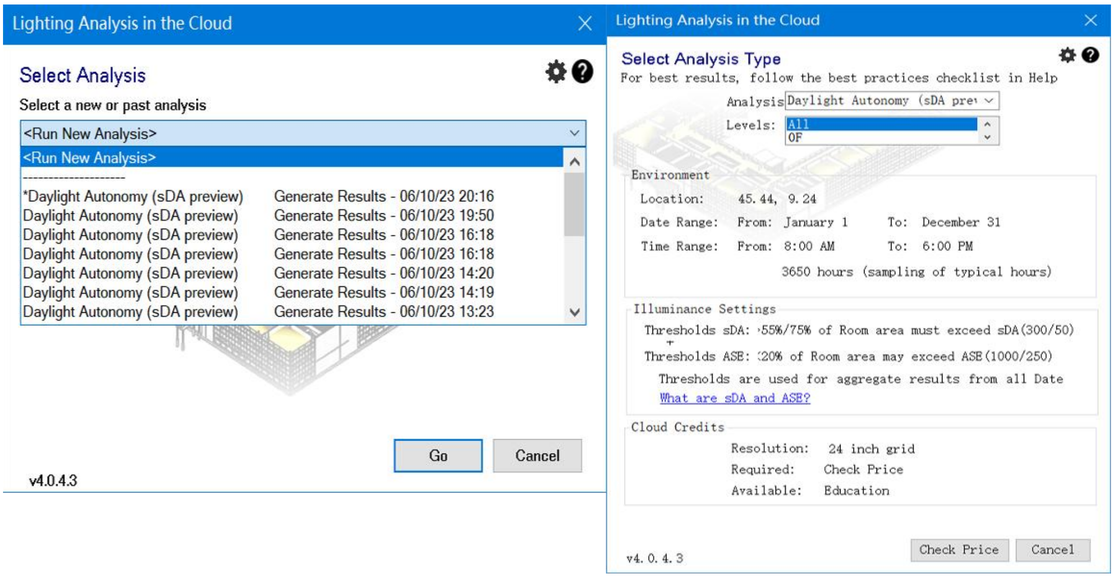


Figure 61. The set of parameters for lighting analysis

The result of the points can be found in the page of Insight and the diagrams are exported to the plans with the name Insight Lighting. Figure 62 shows the result of lighting analysis for the existing design. In the analysis, the yellow part means the areas which satisfy the requirement of spatial daylight autonomy$_{300/50\%}$ (sDA$_{300/50\%}$). The average sDA$_{300/50\%}$ value for the regular occupied floor area is less than 40% because of the shading provided by the cantilever and vegetation on the level of student residence. In addition, the courtyard on the ground floor is not large enough for daylight pouring into the building.

Therefore, for the improvement of the existing design, the cantilever and vegetation around the courtyard on the level of student residence are removed for a better daylight inside the rooms around the courtyard. The daylight can be expanded about 30%. Since the daylight inside the offices around the courtyard is quite poor, some skylights are placed in the roof. And as a result, the daylight inside the offices has a significant increase to about half of the whole area. In addition, the colors of glazing materials and opaque materials are also improved. Figure 63 shows the result of lighting analysis after the improvement.

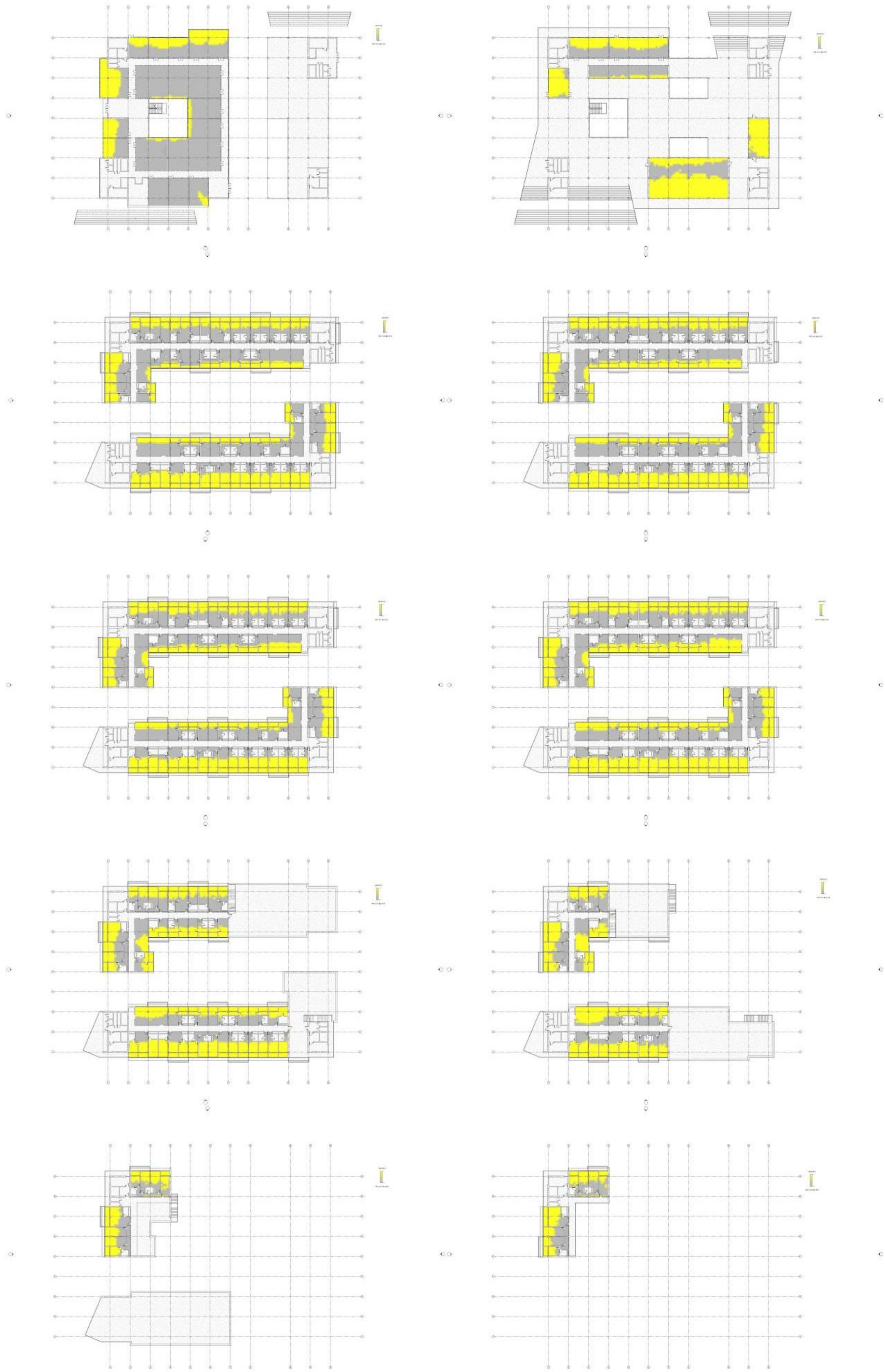


Figure 62. Result of lighting analysis for the existing design

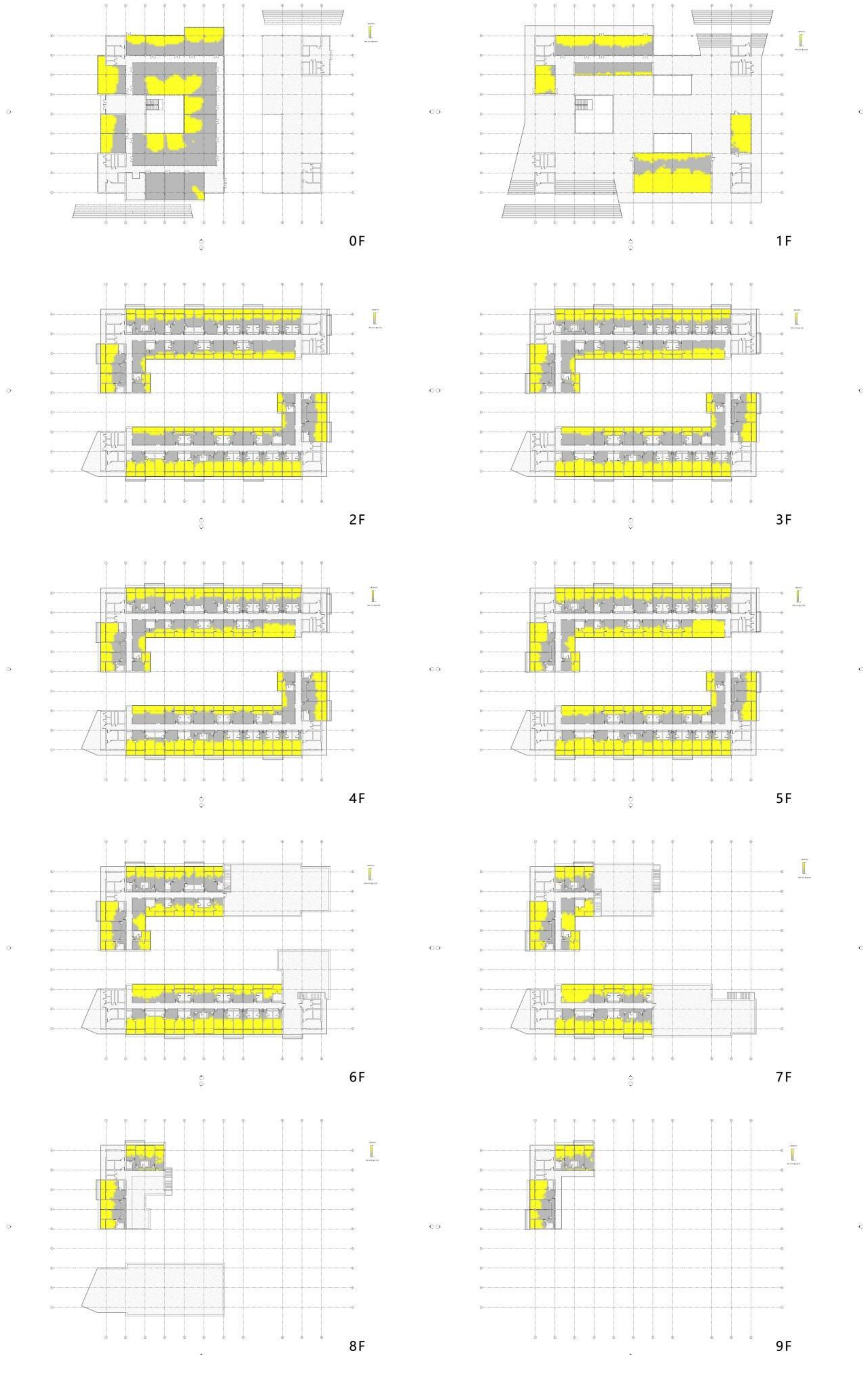


Figure 63. Result of lighting analysis after the improvement

In the schedule of each daylight plan, the $sDA_{300/50\%}$ and $ASE_{1000,250}$ value of each room can be counted as Table 23 shows. The result can be exported into Excel for further calculation of the total $sDA_{300/50\%}$ value. Through the excel, the $sDA_{300/50\%}$ value of each level can be calculated, and then the average $sDA_{300/50\%}$ value can be achieved with the sum of them as Table 24 shows. In summary, the average $sDA_{300/50\%}$ value for the regularly occupied area is 55.18% which means the project can achieve 2 points in this credit.

Table 23

Daylight autonomy (sDA preview) results summary for each room.

Daylight Autonomy (sDA Preview) Results Summary

Building scores 3 LEED points with 76% Building area passing thresholds

At least 55% must exceed sDA300/50 in Rooms with ASE1000/250 < 20% of Room area

B	C	D	E	F	G	H	I	J	K
				sDA 300/50		ASE 1000/250		sDA/ASE	
Name	Numero	Area	Include In Daylighting	%	Points	%	Pass	%	Points
Meeting	-1.03	33 m²	☑						
Meeting	0.01	249 m²	☑	100	3 pt	4	Yes	100	3 pt
Reception	0.02	105 m²	☑	94	3 pt	1	Yes	94	3 pt
Zona Ristoro	0.03	134 m²	☑	98	3 pt	1	Yes	98	3 pt
Meeting	0.04	72 m²	☑	100	3 pt	16	Yes	100	3 pt
Office	0.39	12 m²	☑	100	3 pt	90	No	0	none
Meeting	0.40	13 m²	☑	98	3 pt	0	Yes	98	3 pt
Office	0.38	12 m²	☑	83	3 pt	13	Yes	83	3 pt
Ufficio Open Space	0.35	142 m²	☑	89	3 pt	25	No	0	none
Office	1.02	50 m²	☑	83	3 pt	0	Yes	83	3 pt
Meeting	1.01	36 m²	☑	62	2 pt	8	Yes	62	2 pt
Meeting	1.22	38 m²	☑	38	none	1	Yes	38	none
Office	1.21	19 m²	☑	95	3 pt	4	Yes	95	3 pt
Office	1.04	16 m²	☑	100	3 pt	0	Yes	100	3 pt
Office	1.06	26 m²	☑	34	none	0	Yes	34	none
Office	1.18	27 m²	☑	3	none	2	Yes	3	none
Office	1.37	24 m²	☑	75	3 pt	0	Yes	75	3 pt
Office	1.38	25 m²	☑	83	3 pt	11	Yes	83	3 pt
Office	1.39	34 m²	☑	90	3 pt	19	Yes	90	3 pt
Meeting	1.40	57 m²	☑	75	3 pt	8	Yes	75	3 pt

Table 24

The average $sDA_{300/50\%}$ value of each level and the whole building.

Level	Total area (m^2)	Compliant area (m^2)	$sDA_{300/50}$
0F	1096.37	522.01	47.61%
1F	758.62	455.54	60.04%
2F	1450.36	722.16	49.79%
3F	1450.36	757.54	52.23%
4F	1450.36	793.64	54.72%
5F	1450.36	845.67	58.31%
6F	992.17	619.31	62.42%
7F	610.46	386.77	63.36%
8F	182.05	106.84	58.69%
9F	182.05	100.82	55.38%
Building	9623.16	5310.28	55.18%

6.3.4 EA Prerequisite: Minimum Energy Performance

The intent of the prerequisite is to reduce the environmental and economic harms of excessive energy use by achieving a minimum level of energy efficiency for the building and its systems.

For the prerequisite, the project needs to comply with ANSI/ASHRAE/IESNA Standard 90.1-2016, with errata or a USGBC approved equivalent standard. The Performance Cost Index (PCI) shall be less than or equal to the Performance Cost Index Target (PCI_t) in accordance with the methodology provided in Section 4.2.1.1. The PCI, PCI_t, and percentage improvement are documented with the use of metrics of cost or greenhouse gas (GHG) emissions.

For the calculation, the detailed steps consist of determining climate zones, reviewing ASHRAE mandatory requirements, identifying energy use target for building, selecting option for credit compliance, developing preliminary energy model and ongoing iterations of design phase energy model.

The project satisfies the requirements of the prerequisite and the detailed operations for verification will be displayed in the next chapter.

6.3.5 EA Credit: Optimize Energy Performance

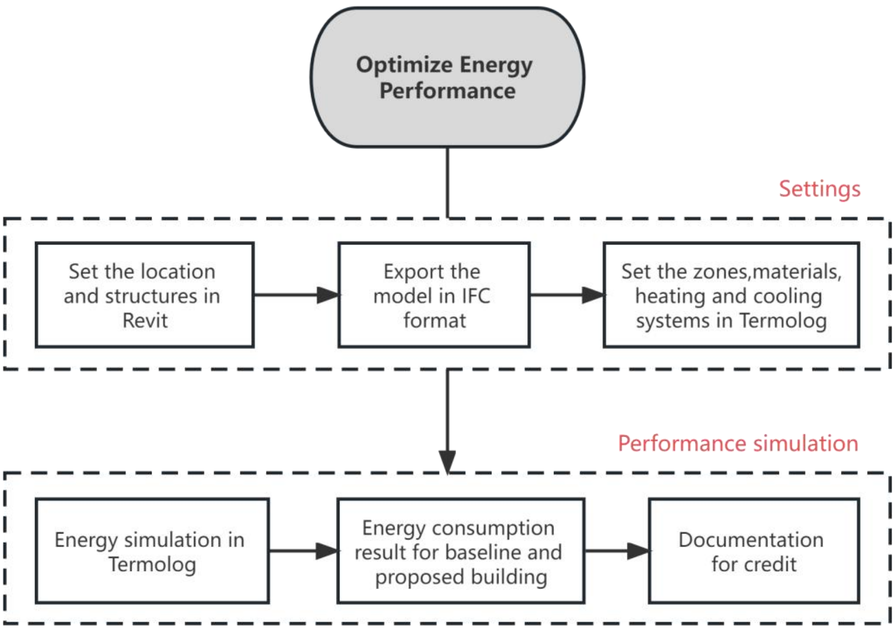


Figure 64. Workflow for the credit

The intent of the credit is to achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic harms associated with excessive energy use.
The credit rewards the project which analyzes efficiency measures during the design process and account for the results in design decision making, focusing on load reduction and HVAC-related strategies (passive measures are acceptable) appropriate for the facility.
For the project, it needs to demonstrate a Performance Cost Index (PCI)1 below the Performance Cost Index Target (PCI_t) calculated in accordance with Section 4.2.1.1 of ANSI/ASHRAE/IESNA Standard 90.1-2016, Appendix G, Table 4.2.1.1. The PCI, PCI_t, and percentage improvement need to be calculated with the use of metrics of cost and greenhouse gas (GHG) emissions. Total points for Leed® have been divided equally between energy cost and greenhouse gas emissions, and are awarded according to Table 25 and Table 26.

Table 25

Points for percentage improvement in energy performance - % Cost PCI below PCI_t.

New Construction	Healthcare, Major Renovation, CS	Points BD+C (except Schools, Healthcare)*	Points Healthcare	Points Schools
5%	2%	1	1	1
10%	5%	2	2	2
15%	10%	3	3	3
20%	15%	4	4	4
25%	20%	5	5	5
30%	25%	6	6	6
35%	30%	7	7	7
40%	35%	8	8	
45%	40%	9	9	8
50%	45%	EP	10	EP
	50%		EP	

Table 26

Points for percentage improvement - % Greenhouse Gas Emissions PCI below PCI_t.

New Construction	Healthcare, Major Renovation, CS,	Points BD+C (except Schools, Healthcare)*	Points Healthcare	Points Schools
5%	2%	1	1	1
10%	5%	2	2	2
16%	10%	3	3	3
24%	16%	4	4	4
32%	24%	5	5	5
40%	32%	6	6	6
50%	40%	7	7	7
65%	50%	8	8	
80%	65%	9	9	8

For the evaluation of the project, the software Termolog is used for building energy performance simulation. Termolog is the BIM software to calculate the energy efficiency of buildings under Lombardy Regional Regulations. For the simulation, the first step is to set the location and type of the work which is the energy diagnostics for the residential building as Figure 65 shows. Figure 66 shows the set of the zones which is based on the settings of rooms in Revit model including area and height. In the project, all the rooms on the same level are included into the same zone, so the whole building has 10 zones for 10 floors in total. For each zone, the domestic hot water system and cooling system are present. And for each room, the gross average height is 3.45m and the average net height is 3.30m.

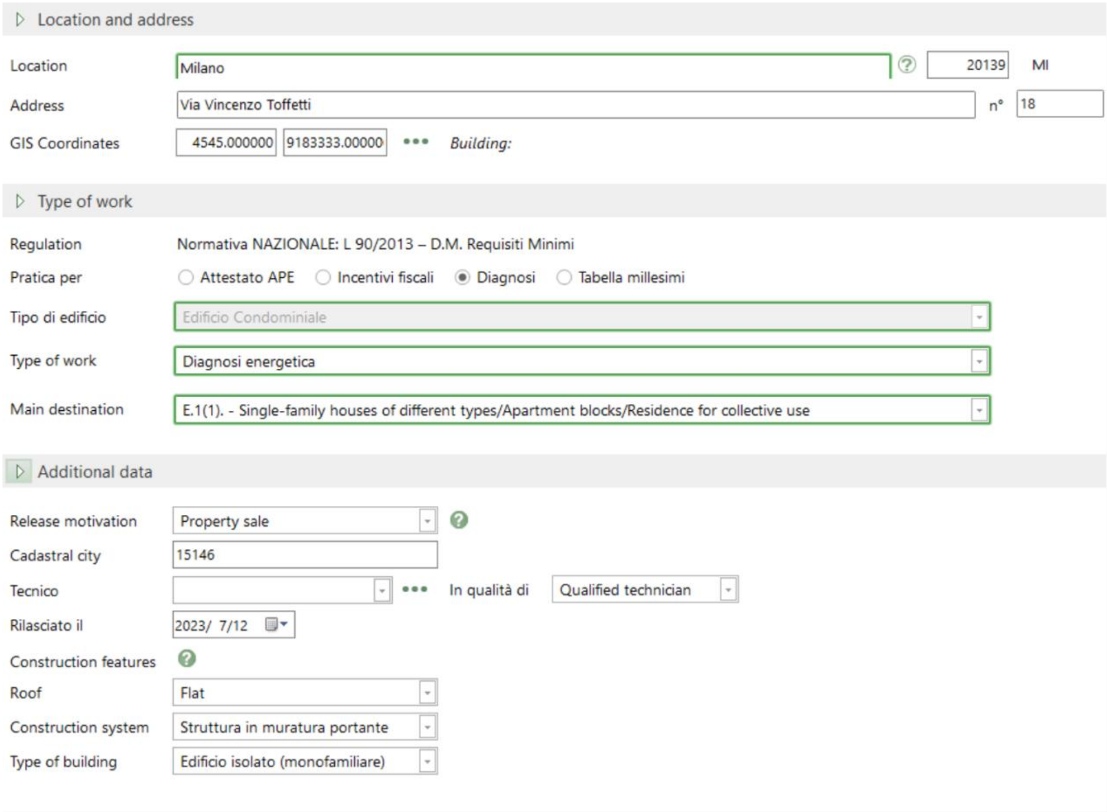


Figure 65. Settings of the location and type of work

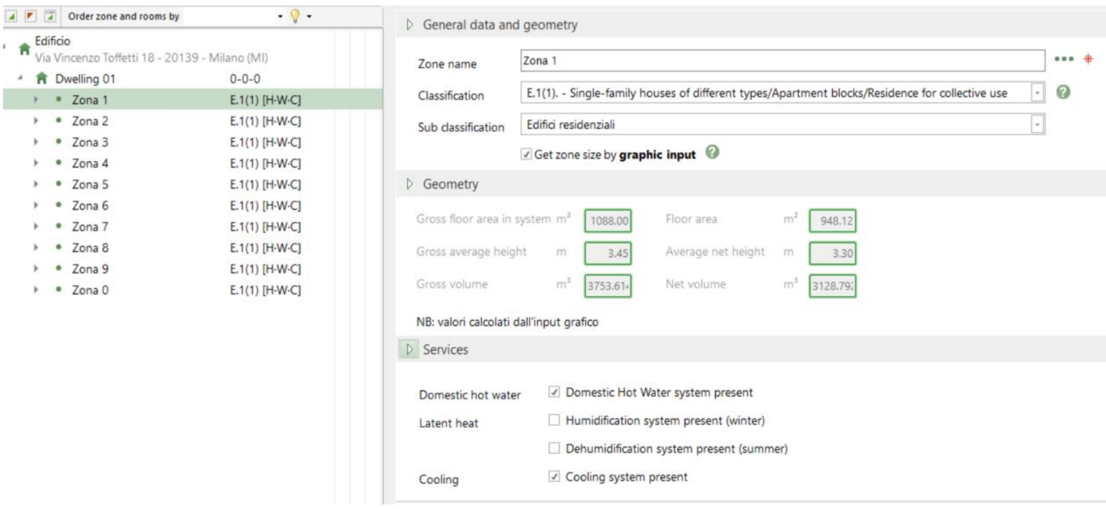


Figure 66. Settings of the building and zones

The next step is the settings for the structures. First the materials and thickness are set in the Revit model based on the material libraries as Figure 67 shows. Then the information of material and thickness can be imported into Termolog in IFC format. In Figure 68, the materials of walls, floors, roofs and windows can be further adjusted based on the archive in Termolog which is more local and reliable.

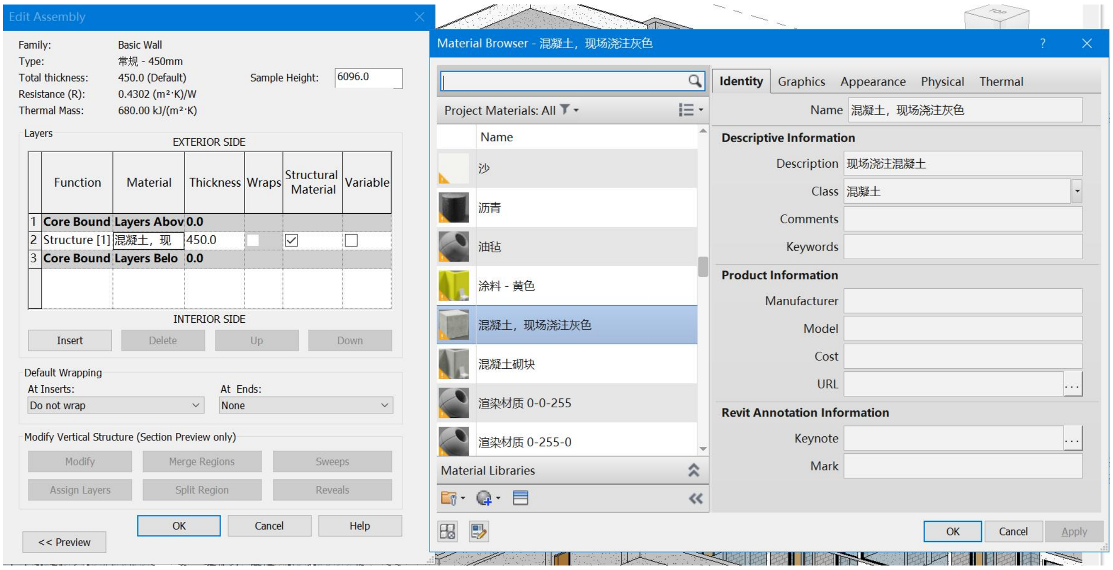


Figure 67. Settings of the materials in Revit model

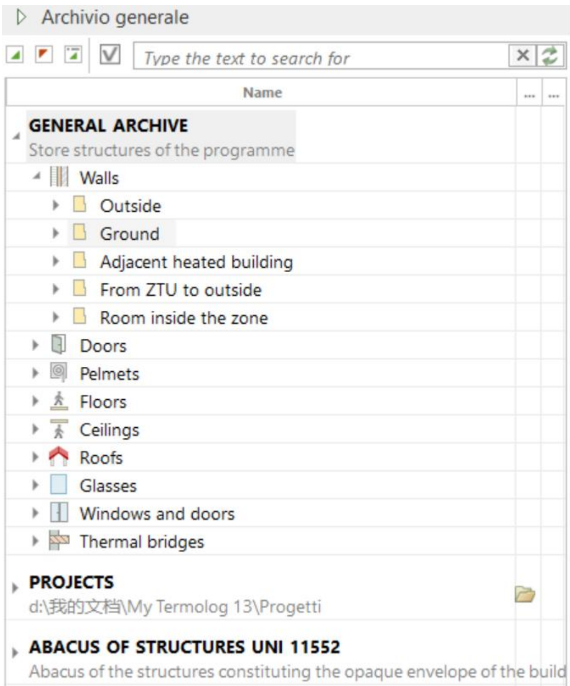


Figure 68. Settings of the materials in Revit model

The parameters of building envelope for the baseline building and proposed building are different. For the parameter of the baseline building, the climate zone of the site can be found in ANSI/ASHRAE/IES Standard 90.1 as Table 27 shows and Milan is in climate zone 4A. The requirements for the building envelope in climate 4A can also be found in the Standard as Table 28 shows and they can be set in Termolog for the simulation of the baseline building. As for the materials of the proposed building, the details of the envelope and U value are designed as Figure 69 shows and also be set in the Termolog for the simulation as shown in Figure 70.

Table 27

International station and climate zones for ASHRAE standard.

Country Location	WMO #	Latitude	Longitude	Climate Zone
LAMEZIA TERME	163620	38.905	16.242	3A
LAMPEDUSA	164900	35.498	12.618	2B
LATINA	162430	41.546	12.91	3A
LECCE	163320	40.238	18.139	3A
MARINA DI GINOSA	163250	40.424	16.887	3B
MESSINA	164200	38.2	15.553	3A
MILANO LINATE	160800	45.445	9.277	4A
MILANO MALPENSA	160660	45.631	8.728	4A
MONTE ARGENTARIO	161680	42.387	11.17	3A
MONTE CIMONE	161340	44.194	10.7	7
MONTE SANT'ANGELO	162580	41.708	15.948	4A
MONTE SCURO	163440	39.331	16.396	5C
MONTE TERMINILLO	162190	42.46	12.985	6A
NAPOLI CAPODICHINO	162890	40.884	14.291	3A

Table 28

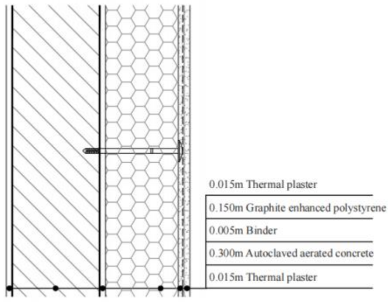
Building envelope requirements for climate zone 4 (A,B,C).

Opaque Elements	*Nonresidential* Assembly Maximum	*Nonresidential* Insulation Min. *R-Value*	*Residential* Assembly Maximum	*Residential* Insulation Min. *R-Value*	Semiheated Assembly Maximum	Semiheated Insulation Min. *R-Value*
Roofs						
Insulation entirely above deck	U-0.184	R-5.3 c.i.	U-0.184	R-5.3 c.i.	U-0.527	R-1.8 c.i.
Metal building[a]	U-0.210	R-3.3 + R-1.9 Ls or R-4.4 + R-1.4 Ls	U-0.210	R-3.3 + R-1.9 Ls or R-4.4 + R-1.4 Ls	U-0.466	R-3.3
Attic and other	U-0.119	R-8.6	U-0.119	R-8.6	U-0.192	R-5.3
Walls, above Grade						
Mass	U-0.592	R-1.7 c.i.	U-0.513	R-2.0 c.i.	U-3.293	NR
Metal building	U-0.341	R-0 + R-2.8 c.i.	U-0.286	R-0 + R-3.3 c.i.	U-0.920	R-2.3
Steel-framed	U-0.365	R-2.3 + R-1.3 c.i.	U-0.365	R-2.3 + R-1.3 c.i.	U-0.705	R-2.3
Wood-framed and other	U-0.365	R-2.3 + R-0.7 c.i. or R-3.5	U-0.365	R-2.3 + R-0.7 c.i. or R-3.5	U-0.504	R-2.3
Wall, below Grade						
Below-grade wall	C-0.678	R-1.3 c.i.	C-0.522	R-1.8 c.i.	C-6.473	NR
Floors						
Mass	U-0.321	R-2.6 c.i.	U-0.287	R-2.9 c.i.	U-0.606	R-1.1 c.i.
Steel joist	U-0.214	R-5.3	U-0.214	R-5.3	U-0.296	R-3.3
Wood-framed and other	U-0.188	R-5.3	U-0.188	R-5.3	U-0.288	R-3.3
Slab-on-Grade Floors						
Unheated	F-0.900	R-2.6 for 600 mm	F-0.900	R-2.6 for 600 mm	F-1.264	NR
Heated	F-1.459	R-3.5 for 600 mm	F-1.191	R-3.5 for 1200 mm	F-1.558	R-1.8 for 600 mm
Opaque Doors						
Swinging	U-2.101		U-2.101		U-2.101	
Nonswinging	U-1.760		U-1.760		U-2.044	

Fenestration	*Nonresidential* Assembly Max. U	*Nonresidential* Assembly Max. *SHGC*	*Nonresidential* Assembly Min. VT/*SHGC*	*Residential* Assembly Max. U	*Residential* Assembly Max. *SHGC*	*Residential* Assembly Min. VT/*SHGC*	Semiheated Assembly Max. U	Semiheated Assembly Max. *SHGC*	Semiheated Assembly Min. VT/*SHGC*
Vertical Fenestration, 0% to 40% of *Wall*		(for all frame types)			(for all frame types)			(for all frame types)	
Nonmetal framing, all	1.76	0.36	1.10	1.76	0.36	1.10	2.90	NR	NR
Metal framing, fixed	2.16			2.16			4.14		
Metal framing, operable	2.61			2.61			4.60		
Metal framing, entrance door	3.86			3.86			4.37		

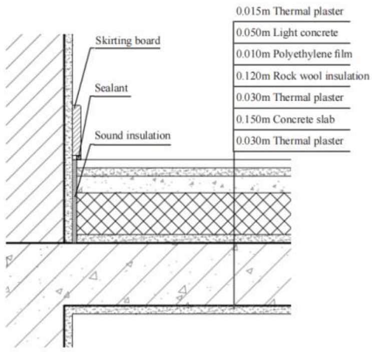
a. External wall construction U value calculation

Construction	Materials	Thickness[m]	Conductivity[W/mK]	Resisitance[m²K/W]
External Wall	Thermal plaster	0.015	0.29	0.05
	Autoclaved aerated concrete	0.30	0.22	1.36
	Graphite enhanced polystyrene	0.15	0.032	4.69
	Thermal plaster	0.015	0.29	0.05
	U VALUE	0. 163<0. 26		



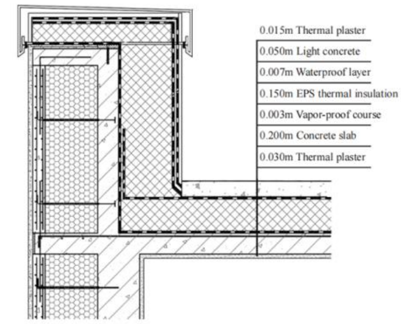
b. Floor construction U value calculation

Construction	Materials	Thickness[m]	Conductivity[W/mK]	Resisitance[m²K/W]
Floor	Thermal plaster	0.015	0.29	0.05
	Light concrete	0.05	0.25	0.20
	Polyethylene film	0.01	0.047	0.21
	Rock wool insulation	0.12	0.038	3.16
	Thermal plaster	0.03	0.29	0.11
	Concrete slab	0.15	1.16	0.13
	Thermal plaster	0.03	0.29	0.11
	U VALUE	0. 236<0. 26		



c. Roof construction U value calculation

Construction	Materials	Thickness[m]	Conductivity[W/mK]	Resisitance[m²K/W]
Roof	Light concrete	0.05	0.25	0.20
	Waterproof layer	0.007	0.17	0.04
	EPS thermal insulation	0.15	0.035	4.29
	Vapor-proof course	0.003	0.055	0.05
	Concrete slab	0.2	1.16	0.17
	Thermal plaster	0.03	0.29	0.11
	U VALUE	0. 206<0. 22		



d. Window construction U value calculation

Construction	Layer discription	Thickness[m]	Solar		SHGC	LSG
			Tsol%	Rsol%		
Window	Optiselec T70XLVT(N)	0.006	25	43	0.29	2.31
	Ar	0.012				
	Optiselec T70XLVT(N)	0.006				
	Optiselec T70XL	0.006				
	U VALUE	0. 81<1. 40				

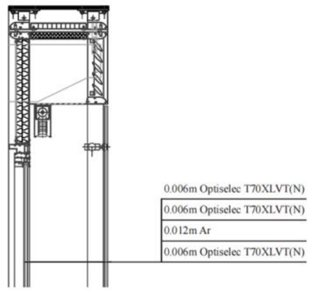


Figure 69. Details and U value of the envelope of proposed building

Strutture dell'edificio

Sort by | Type the text to search for

Struttura	Code	Tipo	To	S	A	U/ψ	C	Use
Walls								
IFC								
200external	pa0046	≡ Parete portrait	Esterno	20.0	-	0.334	7.185	1,898.97
200mm	pa0011	≡ Parete portrait	Esterno	20.0	-	0.334	7.185	22,793.05
450mm	pa0002	≡ Parete portrait	Esterno	45.0	-	0.165	28.019	4,742.92
50mm	pa0059	≡ Parete portrait	Esterno	5.0	-	2.381	8.600	735.18
cover	pa0202	≡ Parete portrait	Esterno	5.0	-	2.381	8.600	780.73
Doors								
IFC								
1200 x 2000mm 2 808002	po0003	∫ Door	Esterno	5.0	-	1.000	10.000	212.94
1500 x 2000mm 457238	po0106	∫ Door	Esterno	5.0	-	1.000	10.000	134.40
700 x 2000mm 3 807348	po0001	∫ Door	Esterno	5.0	-	1.000	10.000	120.40
800 x 2000mm 2 808585	po0019	∫ Door	Esterno	5.0	-	1.000	10.000	660.80
900 x 2000mm 4 450469	po0064	∫ Door	Esterno	5.0	-	1.000	10.000	342.00
Floors								
IFC								
300mm	so0002	≡ Pavimento landscape	Interno	30.0	-	0.218	7.345	23,272.91
300mm 2	so0002	≡ Pavimento landscape	Interno	30.0	-	0.218	25.290	0.00
50mm 2	so0003	≡ Pavimento landscape	Interno	5.0	-	2.174	7.844	0.00
Windows and doors								
IFC								
curtain wall 1034938	se0058	∫ Precalcolato	Esterno	-	8.10	0.810		2,421.90
curtain wall 2 1039049	se0020	∫ Precalcolato	Esterno	-	18.00	0.810		1,026.00
curtain wall 3 992654	se0062	∫ Precalcolato	Esterno	-	3.00	0.810		69.00
curtain wall 4 992653	se0096	∫ Precalcolato	Esterno	-	30.00	0.810		360.00
curtain wall 5 1035289	se0006	∫ Precalcolato	Esterno	-	36.00	0.810		540.00
curtain wall 6 1018440	se0652	∫ Precalcolato	Esterno	-	49.50	0.810		99.00
curtain wall 7 1036199	se0008	∫ Precalcolato	Esterno	-	17.10	0.810		752.40

Figure 70. Settings of materials for the proposed building

In addition, the thermal bridges of each level are set as shown in Figure 71 which includes thermal bridges for inside corner, outside corner, windows and doors. The settings of the zones, rooms, walls, windows and location of thermal bridges can be shown in 2D plans in Figure 72. In addition, Figure 73 shows the result of the energy model, in which the purple ones are windows, white ones are walls, yellow ones are thermal bridges and green ones are roofs and floors.

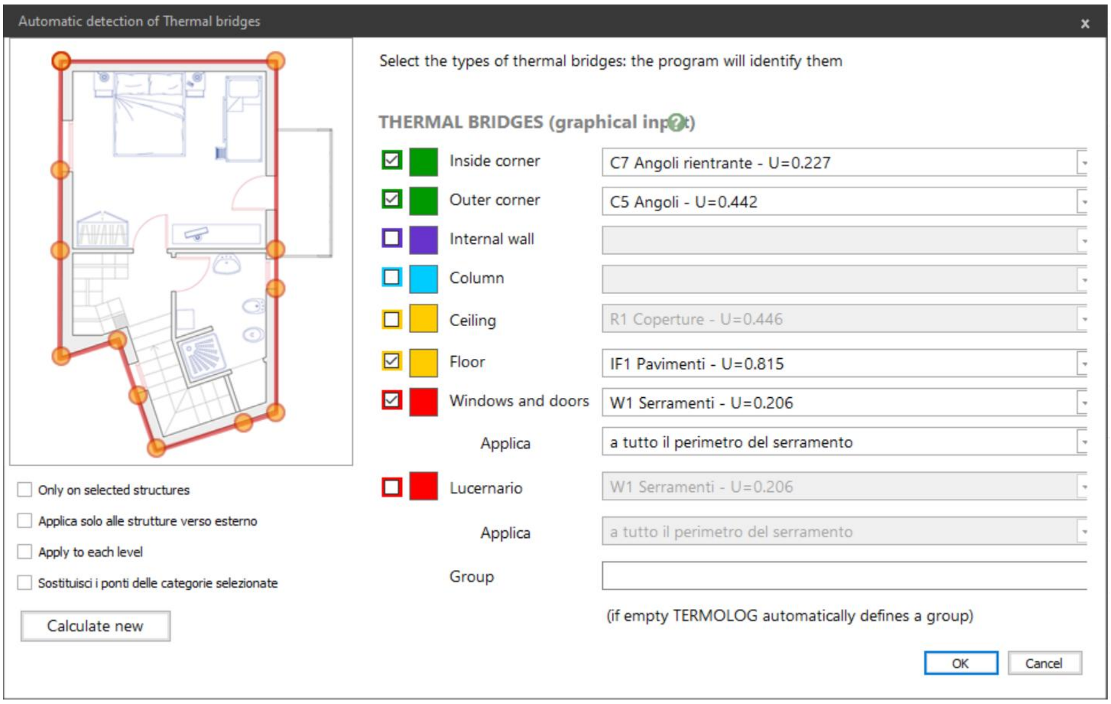


Figure 71. Settings of thermal bridges

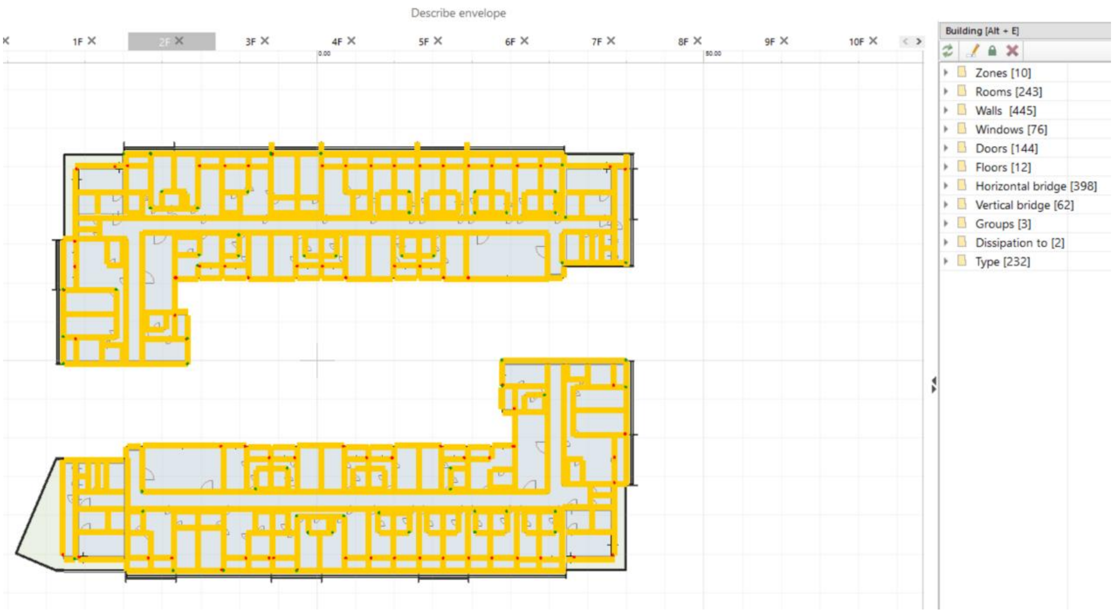


Figure 72. The 2D plan with different components in Termolog

Figure 73. The 3D result of the energy model in Termolog

Figure 74 shows the detailed settings for the heating and cooling systems. The building uses a heat pump and underfloor heating system. The heating system is the tabular-heating distribution system as Figure 75 shows, in which the supply temperature is 50℃ and the return temperature is 40 ℃ with the fuel of electricity.

The pipe is set with insulation. Figure 76 shows the mechanical cooling system with the inner temperature of 19 ℃ and outer temperature of 35 ℃ with the fuel of electricity.

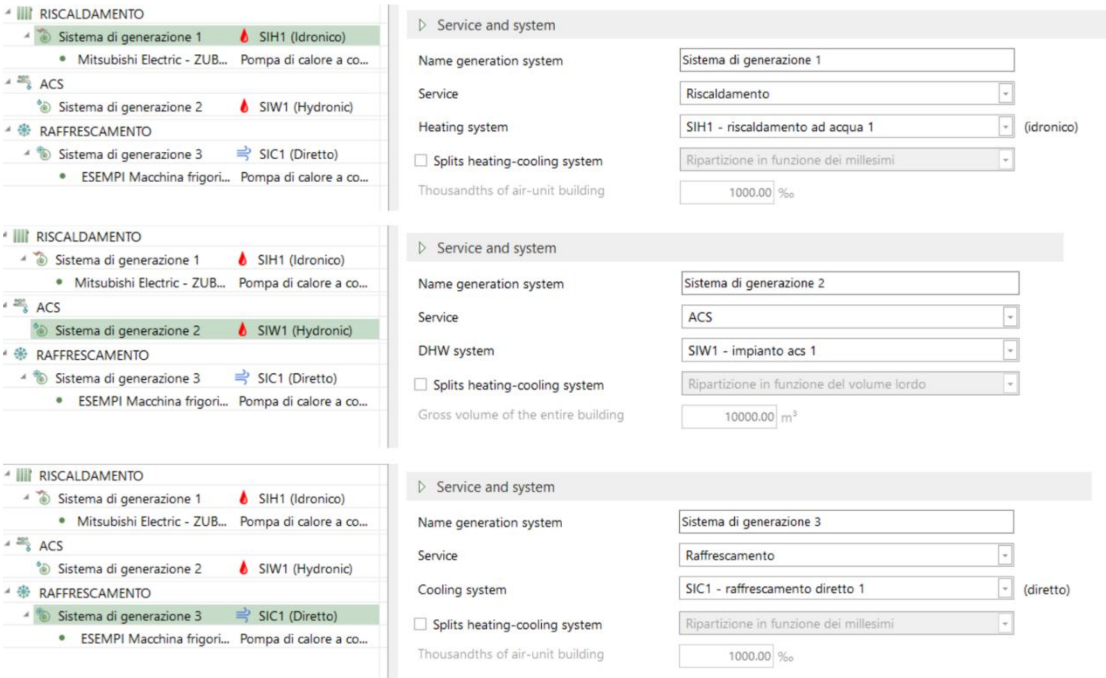


Figure 74. Settings of heating and cooling systems

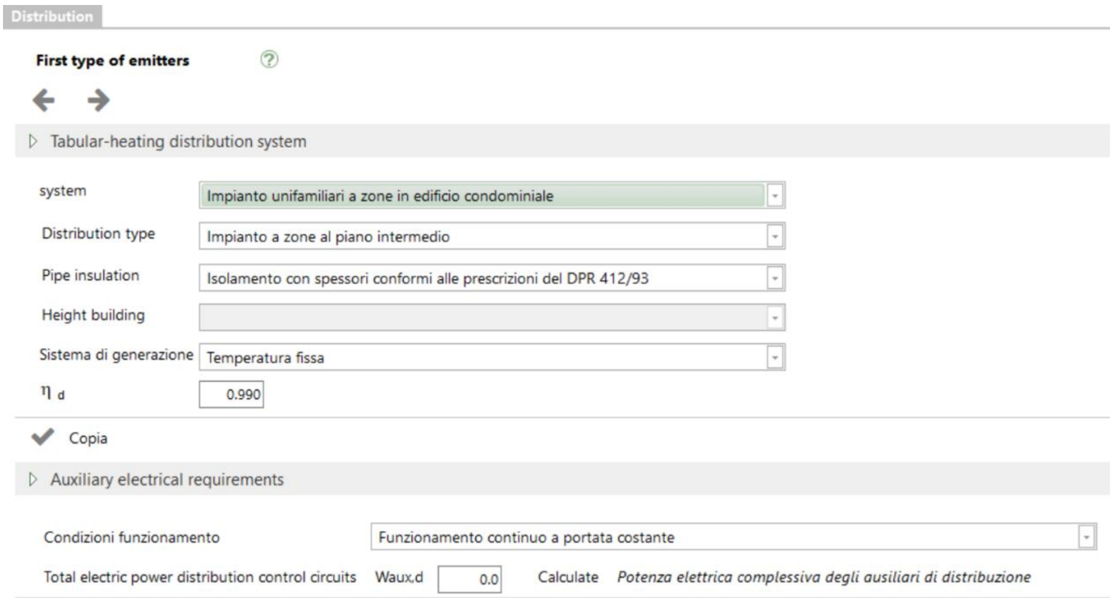


Figure 75. Detailed Settings of tabular-heating distribution system

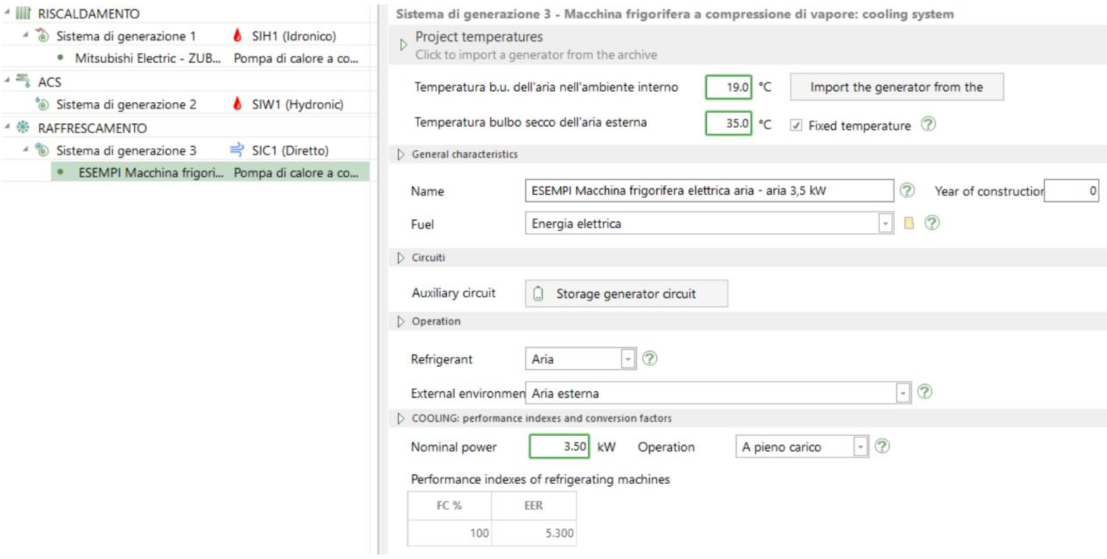


Figure 76. Detailed Settings of mechanical cooling system

Figure 77, 78 show the energy simulation result for the baseline and proposed building. The total simulated area is 14798m^2 and the total simulated volume is 60788m^3. The cooling and heating systems each work for half a year and EP glnr of the building goes through a decrease from 23.11 kWh/m^2/year to 13.52 kWh/m^2/year which decrease by 41.5%. According to the tables in Leed® standard, the project can earn 8 points for energy cost reduction and 6 points for greenhouse gas reduction, which means the project can achieve 14 points in total in this credit.

Classificazione dell'edificio secondo Normativa NAZIONALE: L 90/2013 – D.M. Requisiti Minimi - Intero edificio

Dati geometrici

Superficie utile riscaldata	Su,H	14.797,69	m²
Superficie utile raffrescata	Su,C	14.797,69	m²
Volume lordo riscaldato	V,H	60.788,34	m³
Volume lordo raffrescato	V,C	60.788,34	m³
Superficie disperdente	Sdisp	37.823,48	m²

Fabbisogni di energia termica utile

EPH,nd	90,35 kWh/m²	*Durata*	*183 giorni*
EPC,nd	27,01 kWh/m²	*Durata*	*182 giorni*
EPW,nd	0,18 kWh/m²		

Fabbisogni di energia primaria

EPH,ren	2,48 kWh/m²	EPH,nren	1,57 kWh/m²	EPH,tot	4,05 kWh/m²	ηH	22,329
EPC,ren	2,88 kWh/m²	EPC,nren	11,96 kWh/m²	EPC,tot	14,84 kWh/m²	ηC	1,820
EPW,ren	0,00 kWh/m²	EPW,nren	0,00 kWh/m²	EPW,tot	0,00 kWh/m²	ηW	1,000
EPgl,ren	5,36 kWh/m²	EPgl,nren	13,52 kWh/m²	EPgl,tot	18,89 kWh/m²		

Figure 77. Energy consumption result for the proposed building

Figure 78. Comparison between the baseline and proposed building

6.3.6 EA Credit: Renewable Energy

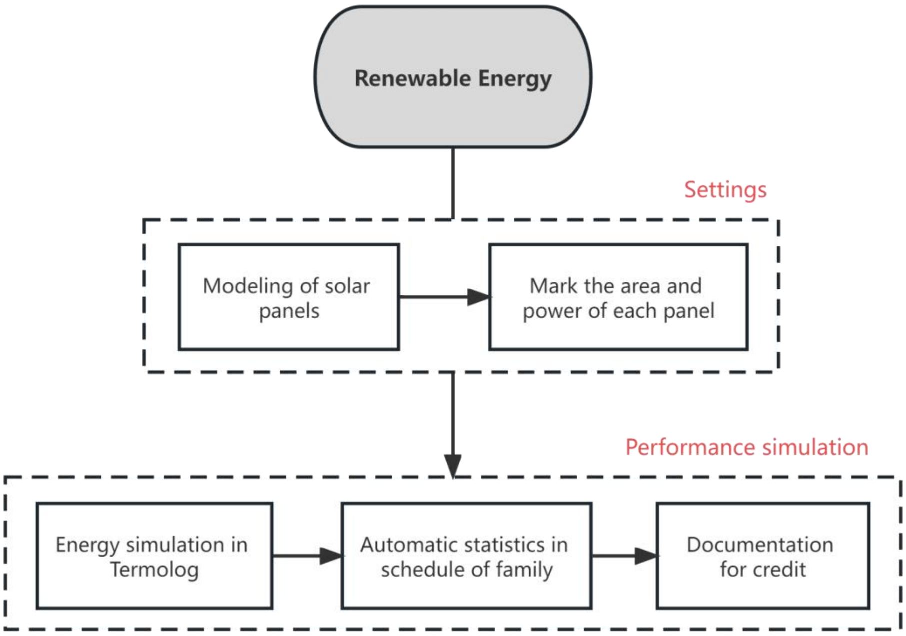


Figure 79. Workflow for the credit

The intent of the credit is to reduce the environmental and economic harms associated with fossil fuel energy and reduce greenhouse gas emissions by increasing the supply of renewable energy and carbon mitigation projects.

The credit rewards the project which uses on-site renewable energy systems, procure renewable energy from offsite sources, or offset the greenhouse gas emissions from all or a portion of the building's annual energy use. It should choose one or more strategies for renewable energy procurement from the categories for a total of 5 points as Table 29 shows:

Tier 1: On-site renewable energy generation;

Tier 2: Off-site renewable energy produced by a generation asset(s) built within the last 5 years, and generated by either an asset(s) in the project's grid subregion or an asset(s) in a grid subregion with higher greenhouse gas emissions rates;

Tier 3: Off-site renewable energy that is produced by a generation asset(s) built within the last 5 years;
Tier 4: Off-site renewable energy that is Green-e Energy certified;
Tier 5: Off-site renewable energy that is produced by a generation asset(s) that meet Green-e's certification criteria (or equivalent).

Table 29
Points for renewable energy procurement.

Points	Tier 1	Tier 2		Tier 3		Tier 4		Tier 5	
		15-Year	1-Year	15-Year	1-Year	15-Year	1-Year	15-Year	1-Year
1	2%	20%	150%	30%	225%	40%	300%	50%	375%
2	5%	30%	225%	40%	300%	60%	450%	75%	562.5%
3	10%	40%	300%	50%	375%	80%	600%		
4	20%	50%	375%	60%	450%				
5	40%	60%	450%	70%	525%				
EP	60%	70%	525%	80%	600%	100%	750%	100%	750%

For the project, it will use Tier 1: On-site renewable energy generation. The on-site renewable energy comes from the solar panels on the roofs of the building. For the calculation of the energy generated by the solar panels, first the solar panels from the component library are built in the Revit model as shown in Figure 80. Then the schedule of furniture can calculate the number and total area of the solar panels under the same family automatically.

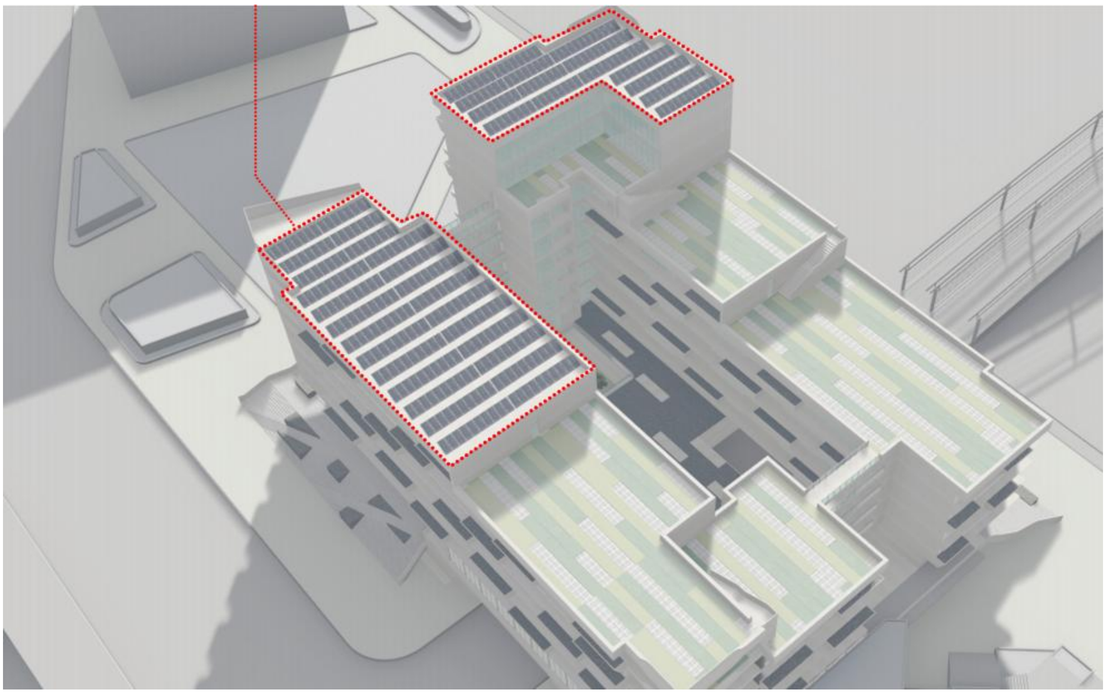


Figure 80. Solar panels in Revit model

The selection of the solar panel is based on the list of best solar panels in energy efficiency as shown in Table 30. The project chooses the SunPower M-series solar panel which has the largest energy efficiency (Figure 81). Table 31 shows the detailed parameter of the solar panel with the power density of 228.2 W/m^2, energy efficiency of 22.8% and production of electricity of 172.8kWh/m^2/year.

Table 30

List of best solar panels in energy efficiency in January 2023.

	Top 10 Solar panels – January 2023					
Rank	**Manufacturer**	**Model**	**Technology**	**Efficiency**	**Power Density**	**Power**
1	SUNPOWER	Maxecon 6 AC	IBC	**22.8%**	228.2 W/m2	440 W
2	SUNPOWER	Maxeon 3 SPR-MAX3-430	IBC	**22.7%**	226.9W/m2	430 W
3	JinKO Solar	Tiger NeoJKM585N-72HL4-V	TOPCon	**22.65%**	226.45W/m2	585 W
4	LONGi	Hi-Mo 6LR5-72HTH-585M	HPBC	**22.6%**	226.46 W/m2	585 W
5	HUASUN 华晟新能源	HS-210-B132 DS700	HJT	**22.5%**	225.34 W/m2	700 W
6	RECOM TECHNOLOGIES	RCM-700-8DBHM	HJT	**22.5%**	225.34W/m2	700 W
7	CanadianSolar	HiHero CS6R 440H-AG	HJT	**22.5%**	225.32 W/m2	440 W
8	SUNOVA SOLAR	SS-575-72MDH(T)	PERCHalf Cell	**22.3%**	222.6 W/m2	575 W
9	REC	Pure-R	HJT	**22.3%**	223 W/m2	430 W
10	JinKO Solar	60 HL4-(V)	TOPCon	**22.24%**	222.4 W/m2	480 W

Figure 81. SunPower M-series solar panel

Table 31

Detailed parameter of SunPower M-series solar panel.

Wattage	420 W - 440 W
Efficiency rating	21.7% - 22.8%
Power tolerance	-0/+5%
Cell type	Monocrystalline Maxeon Gen 6
Product warranty	25 years
Performance warranty	25 years; 98% power capacity after Year 1; no more than 0.25% annual degradation until Year 25

The result can be exported into Excel for further calculation as Table 32 shows. According to the schedule of furniture, the total area of solar panels is 488 square meters which can produce 84326.4 kWh of energy per year while the whole building consumes 200068.96 kWh of energy per year. As a result, the solar panels can produce 42.1% for the energy consumption of the whole building and so the project can achieve 5 points for this credit.

Table 32

Calculation of on-site renewable energy procurement.

Name	Total area (m2)	Power density (kWh/m2/year)	Amount of energy (kWh/year)
Building consumption	14798	13.52	200068.96
Solar panel	488	172.8	84326.4
Ratio	42.1%		

6.3.7 MR Credit: Building Life-Cycle Impact Reduction

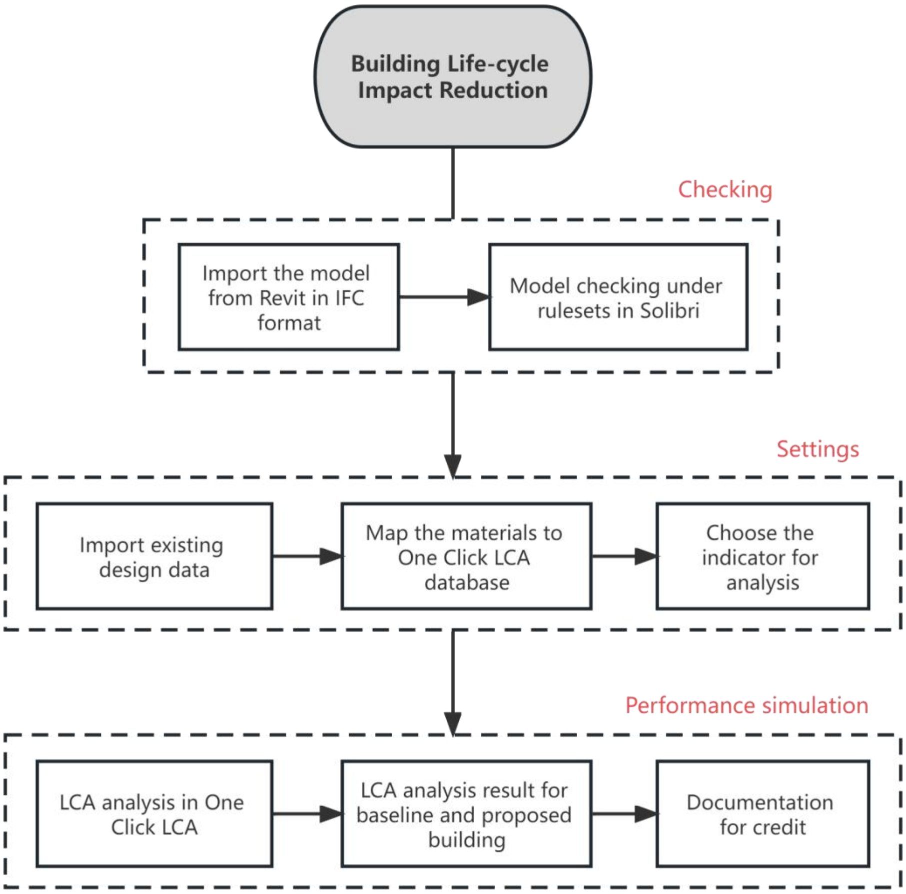


Figure 82. Workflow for the credit

The intent of the credit is to encourage adaptive reuse and optimize the environmental performance of products and materials.

The credit rewards the project which can demonstrate reduced environmental effects during initial project decision-making by reusing existing building resources or demonstrating a reduction in materials use through life-cycle assessment. In detail, the project needs to conduct a life-cycle assessment of the project's structure and enclosure and select one or more of the following paths below to earn up to 4 points:

Path 1: Conduct a life cycle assessment of the project's structure and enclosure (1 point).

Path 2: Conduct a life cycle assessment of the project's structure and enclosure that demonstrates a minimum of 5% reduction, compared with a baseline building in at least three of the six impact categories listed below, one of which must be global warming potential (2 points).

Path 3: Conduct a life cycle assessment of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories listed below, one of which must be global warming potential (3 points).

Path 4: Meet requirements of Path 3 and incorporate building reuse and/or salvage materials into the project's structure and enclosure for the proposed design. Demonstrate reductions compared with a baseline building of at least 20% reduction for global warming potential and demonstrate at least 10% reduction in two additional impact categories listed below (4 points).

For the six impact categories for reduction, they consist of:

a. global warming potential (greenhouse gases), in kg CO_2e;
b. depletion of the stratospheric ozone layer, in kg CFC-11e;
c. acidification of land and water sources, in moles H^+ or kg SO_2e;
d. eutrophication, in kg nitrogen eq or kg phosphate eq;
e. formation of tropospheric ozone, in kg NO_x, kg O_3 eq, or kg ethene; and
f. depletion of nonrenewable energy resources, in MJ using CML / depletion of fossil fuels in TRACI.

For the project, it will use the software One Click LCA for conducting the life cycle assessment of the project's structure and enclosure. Before the simulation, the software Solibri needs to be introduced for model checking. Solibri can combine models from different disciplines and run highly advanced checks on the federated model against BIM requirements and regulations, going way beyond simple clash detection. Figure 83 shows the flow of how Solibri works.

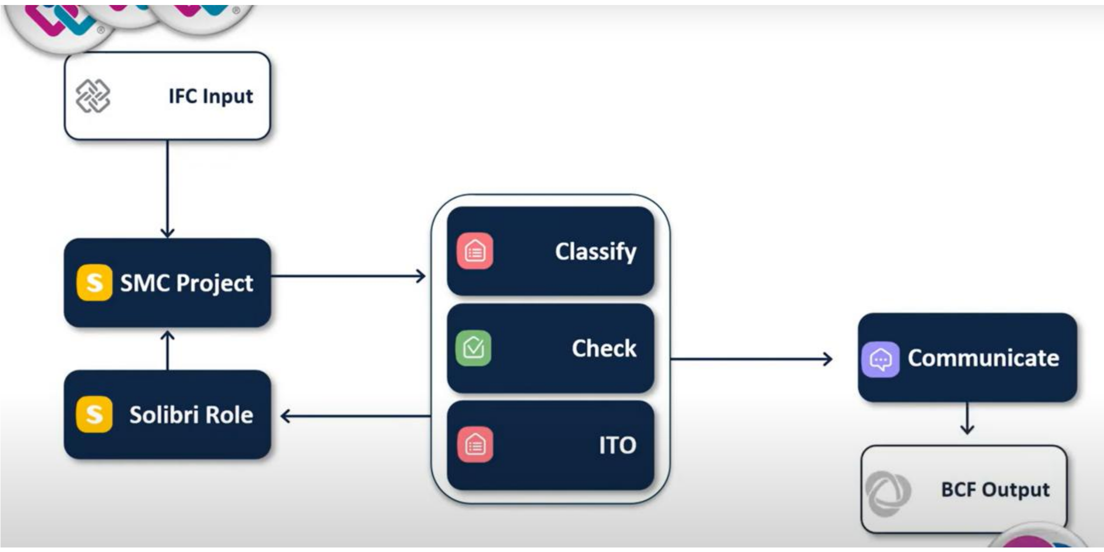


Figure 83. The flow of how Solibri works

The model can be imported into Solibri in IFC format from Revit model. In Solibri, each kind of component like columns, walls and windows can be isolated, and sections can be cut to check the combination between each component as Figure 84 shows. Then the spaces, functions and building elements can be classified in different colors for better control in Figure 85.

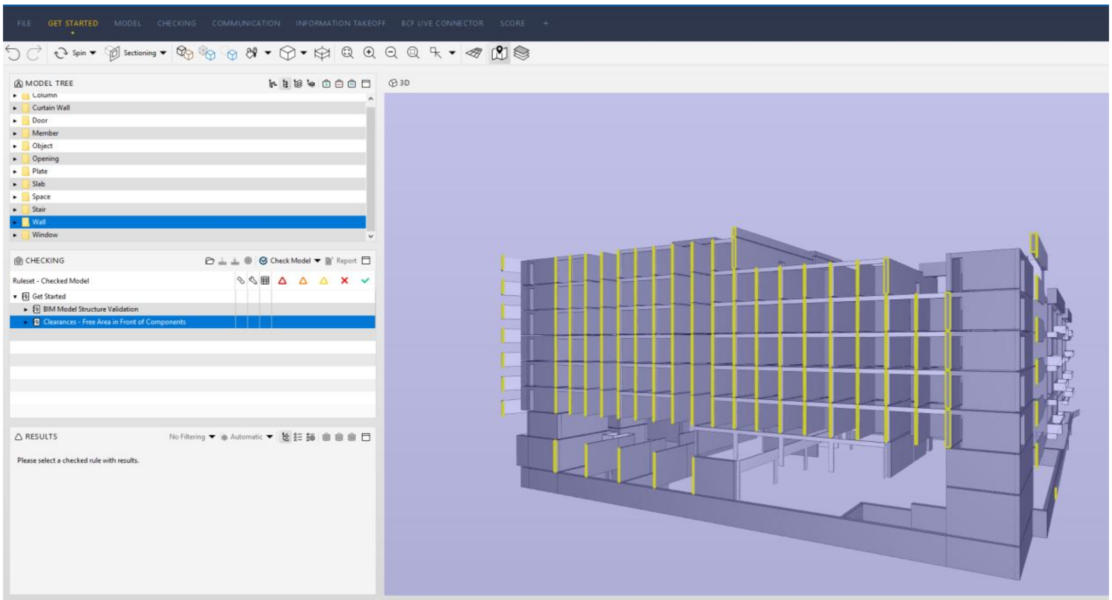


Figure 84. The isolated components and section in Solibri

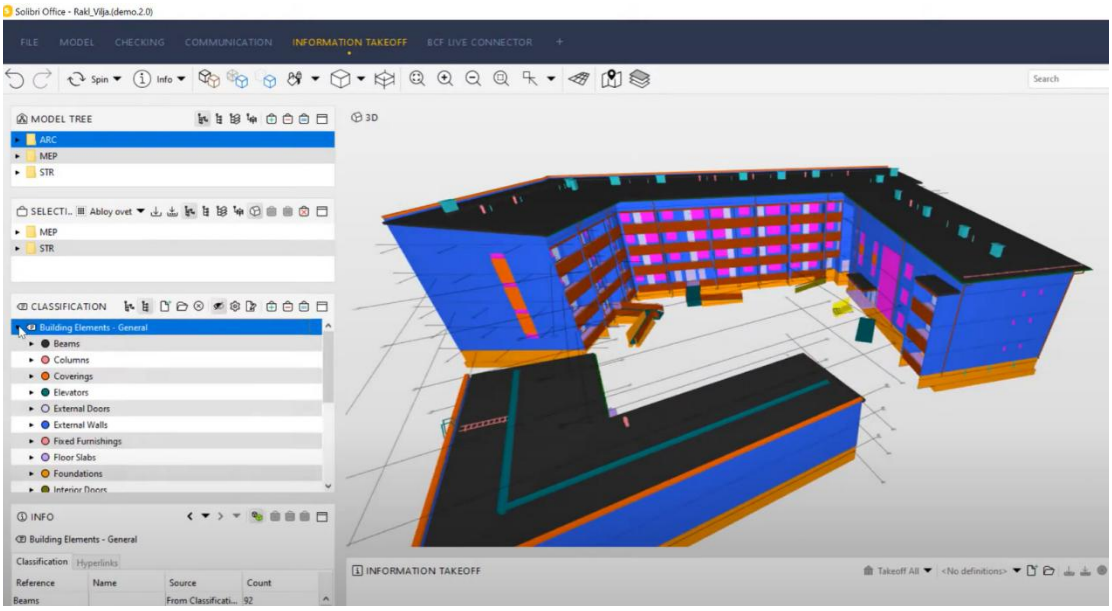


Figure 85. The settings for classification in Solibri

For the model checking, several rulesets in Solibri can be added to have a flash detection on the problems of the model. For example, Figure 86 shows how Solibri detects if there is any distance between other components and the columns. If everything is fine, it will show OK in the checklist, or it will point out the component with a mistake and it can be isolated to solve. In addition, the space validation can be checked to see the quality of walls and clearances of windows and doors can be checked to make sure they can be open. In Figure 87, the ruleset manager can perform different kinds of checks in the library.

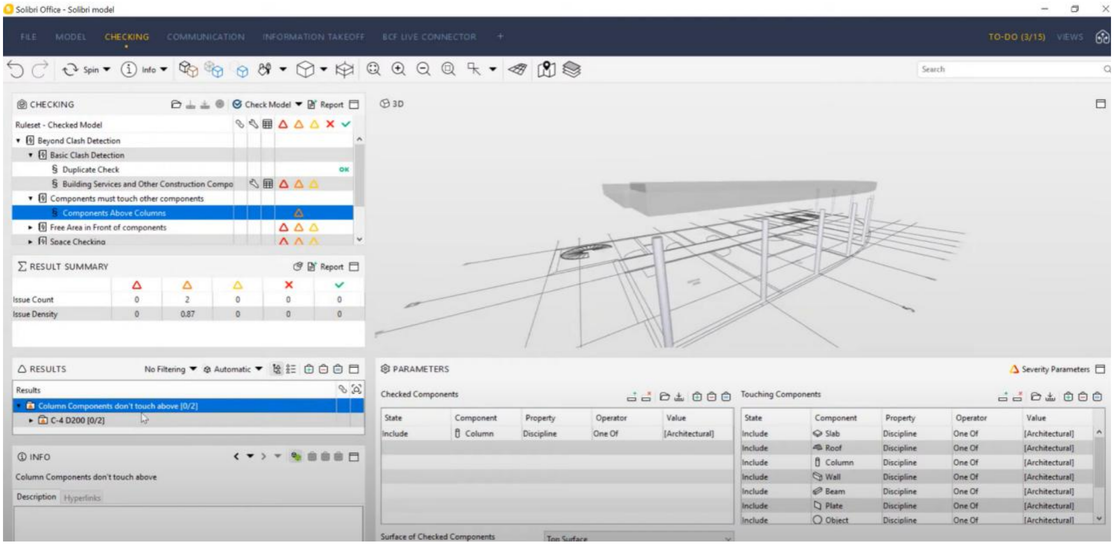


Figure 86. Model checking for columns in Solibri

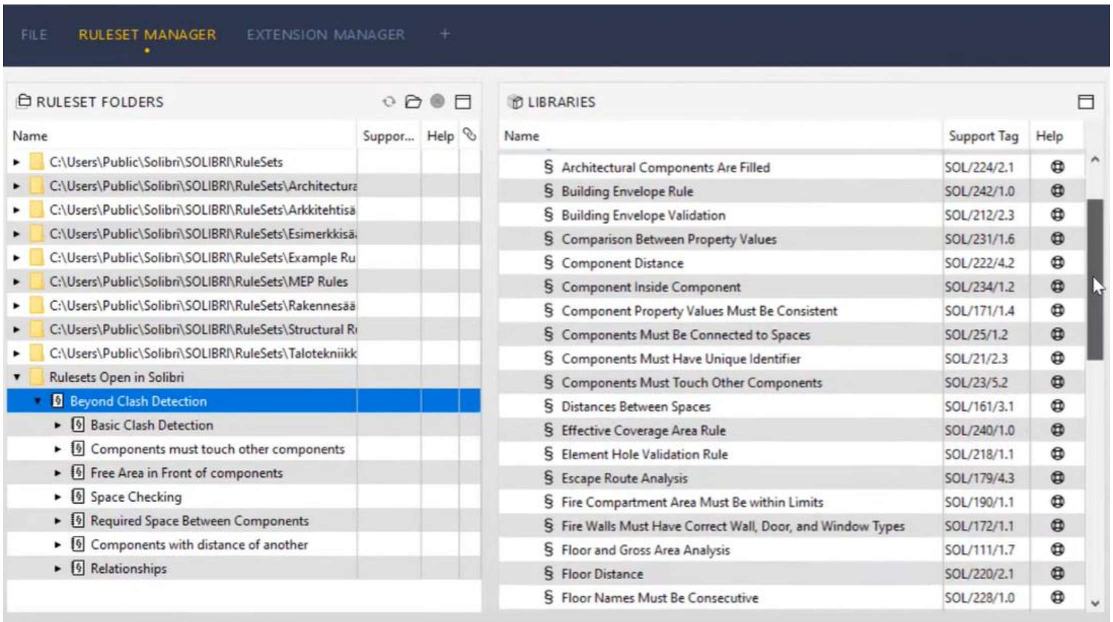


Figure 87. The ruleset manager in Solibri

After the model checking, a better qualified model can be achieved in Revit. The next step is to conduct the life cycle assessment of the project's structure and enclosure. Figure 88 shows the flow of how to get Leed® credits with the use of One Click LCA from importing existing design, creating baseline design, developing alternatives to getting LCA reports for LEED®. One Click LCA can be inserted into Revit as a plug-in as Figure 89 shows. Different categories like floors, columns, framing and walls can be included and the unit in which the materials will be exported for result can also be set.

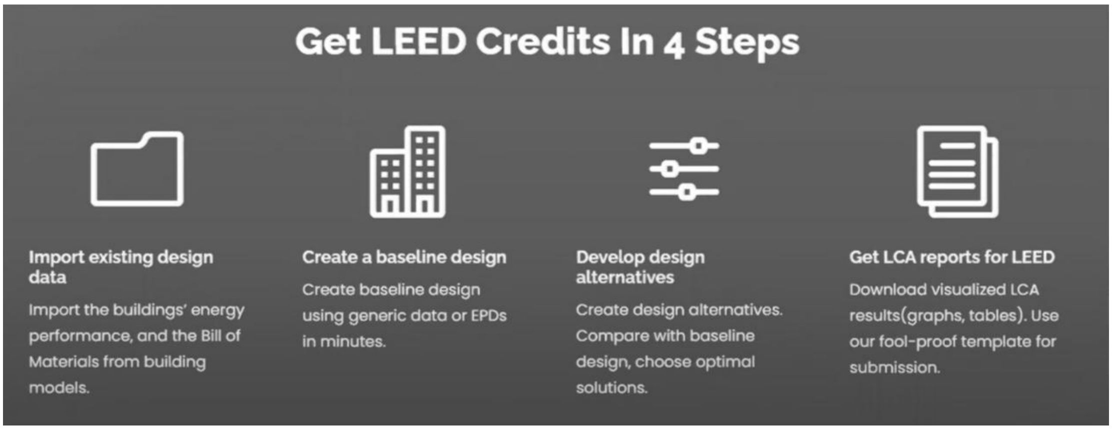


Figure 88. The flow of how to get Leed credits with One Click LCA

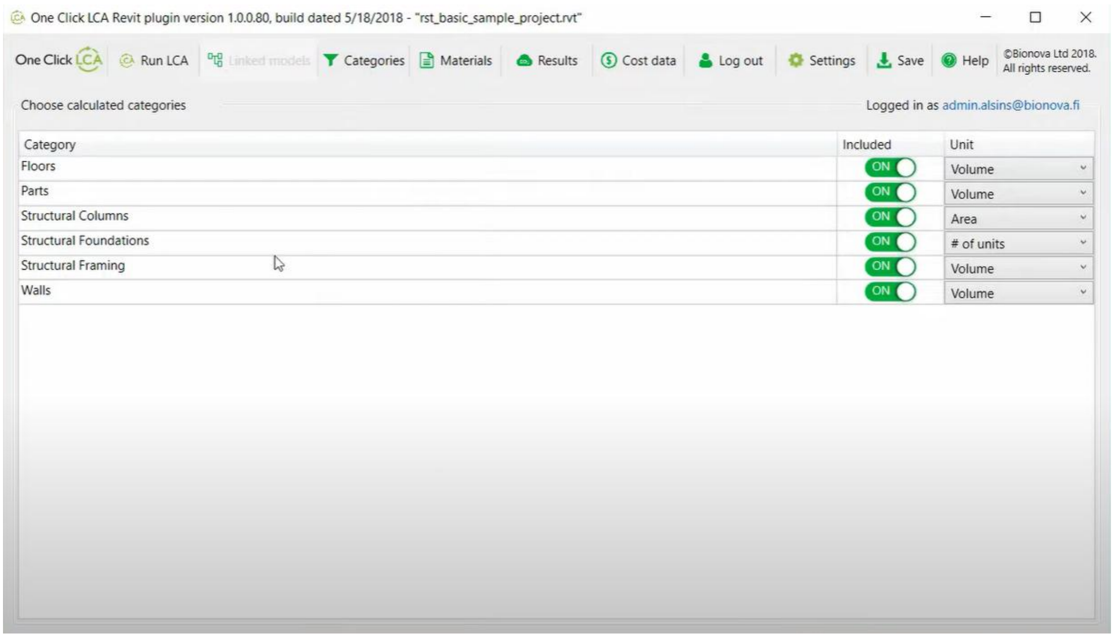


Figure 89. One Click LCA plug-in for Revit

Then in the materials tab as Figure 90 shows, the material components of each category can be found and the materials can be mapped to the One Click LCA database. The data domain can be set and the materials can be filtered by type or country according to the requirements of the baseline and alternative design. The material which is set can be isolated in the model for a better check. After mapping all the materials, they can be saved and applied to the Revit model.

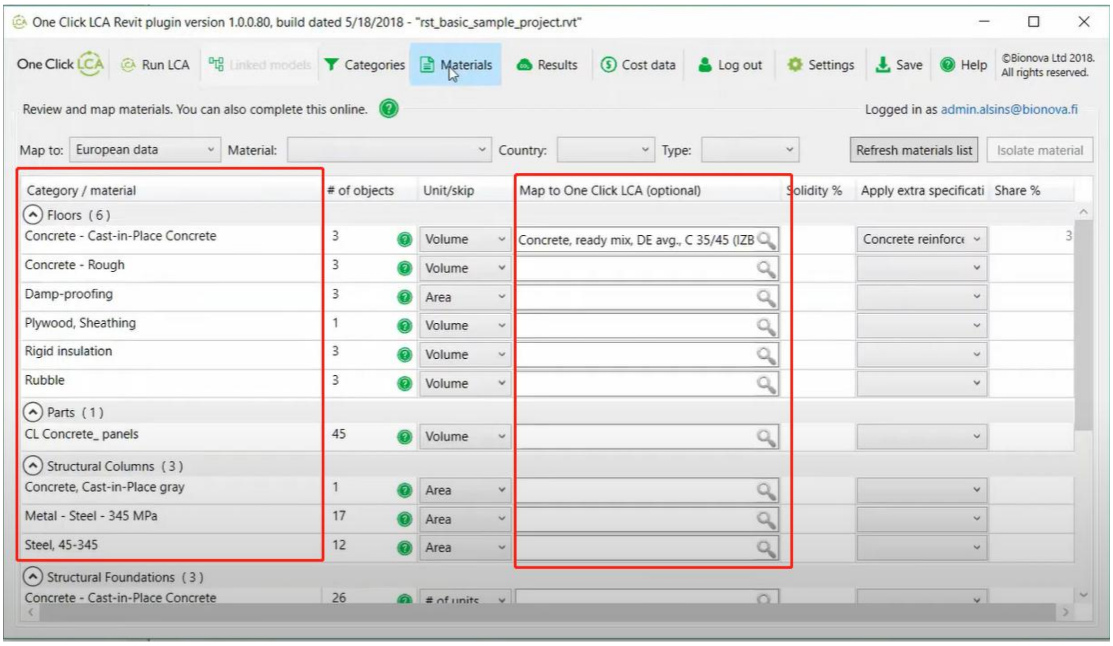


Figure 90. The materials tab of One Click LCA plug-in

The last step is to run the LCA analysis. After clicking on the tab, the plug-in will be redirected to the One Click LCA web application as Figure 91 shows. The name and stage of the design like concept design or developed design can be set, and the data from Revit can be imported for the LCA and LCC analysis. Figure 92 shows the final result of the whole-building life cycle assessment, in which six kinds of impact categories for reduction can be calculated together, and the result can be divided into different life cycle stages.

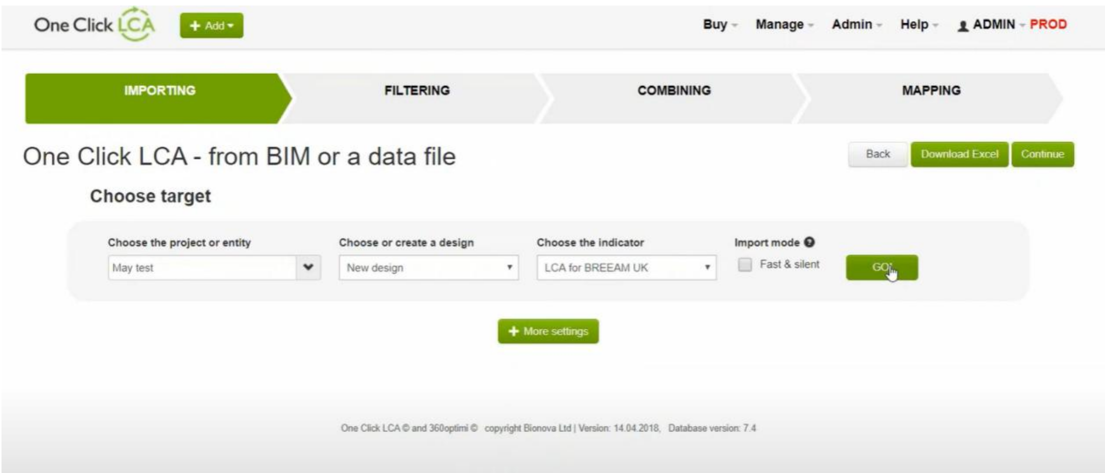
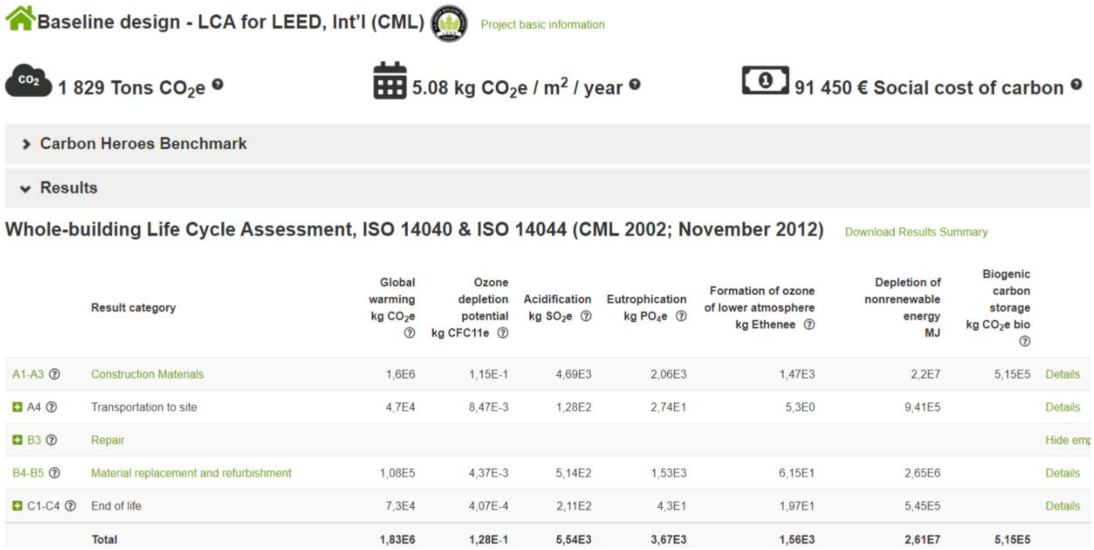


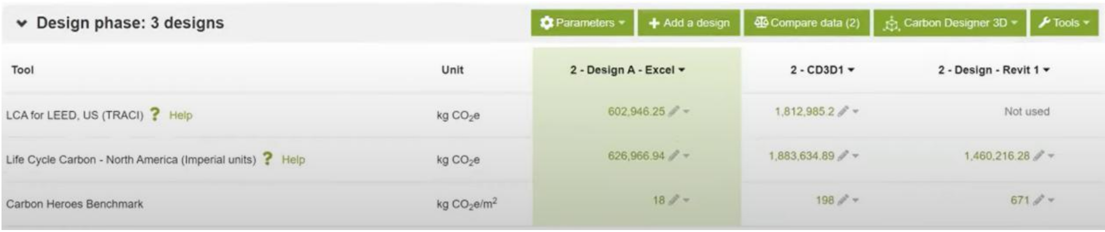
Figure 91. The interface of One Click LCA web application



	Result category	Global warming kg CO_2e	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Depletion of nonrenewable energy MJ	Biogenic carbon storage kg CO_2e bio	
A1-A3	Construction Materials	1,6E6	1,15E-1	4,69E3	2,06E3	1,47E3	2,2E7	5,15E5	Details
A4	Transportation to site	4,7E4	8,47E-3	1,28E2	2,74E1	5,3E0	9,41E5		Details
B3	Repair								Hide emp
B4-B5	Material replacement and refurbishment	1,08E5	4,37E-3	5,14E2	1,53E3	6,15E1	2,65E6		Details
C1-C4	End of life	7,3E4	4,07E-4	2,11E2	4,3E1	1,97E1	5,45E5		Details
	Total	1,83E6	1,28E-1	5,54E3	3,67E3	1,56E3	2,61E7	5,15E5	

Figure 92. The final result for the whole-building life cycle assessment

The result for the baseline and alternative design can be compared together in One Click LCA as Figure 93 shows in which the reduction on the impact categories can be demonstrated. In addition, the comparison of the simulation results between different life cycle stages and classifications can also be demonstrated in pie chart, bar chart or column chart as Figure 94 shows. In summary, with the help of One Click LCA on whole-building life cycle assessment, the project can achieve up to 4 points in this credit.



Tool	Unit	2 - Design A - Excel	2 - CD3D1	2 - Design - Revit 1
LCA for LEED, US (TRACI) ? Help	kg CO_2e	602,946.25	1,812,985.2	Not used
Life Cycle Carbon - North America (Imperial units) ? Help	kg CO_2e	626,966.94	1,883,634.89	1,460,216.28
Carbon Heroes Benchmark	kg CO_2e/m^2	18	198	671

Figure 93. The comparison of result between different designs in One Click LCA

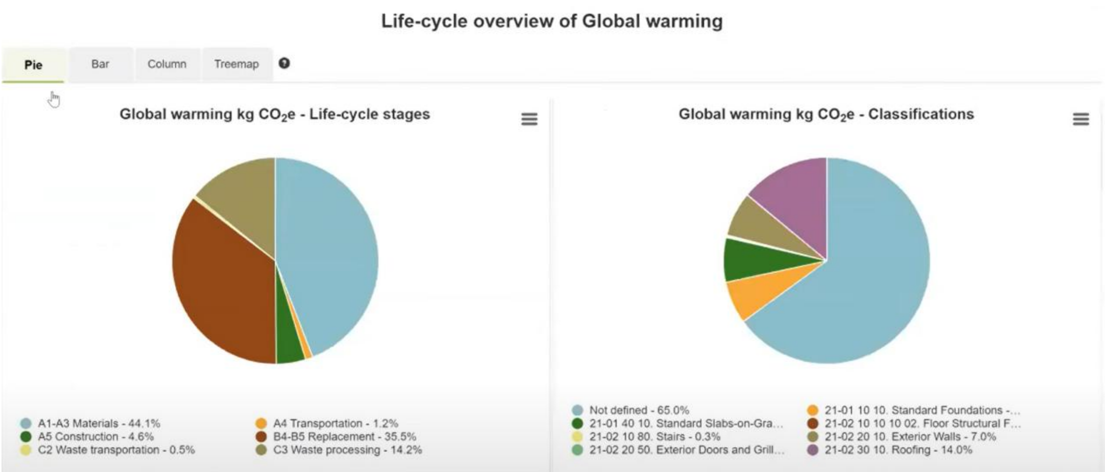


Figure 94. The comparison of result between different stages in One Click LCA

6.3.8 MR Credit: Building Product Disclosure and Optimization - Environmental Product Declarations

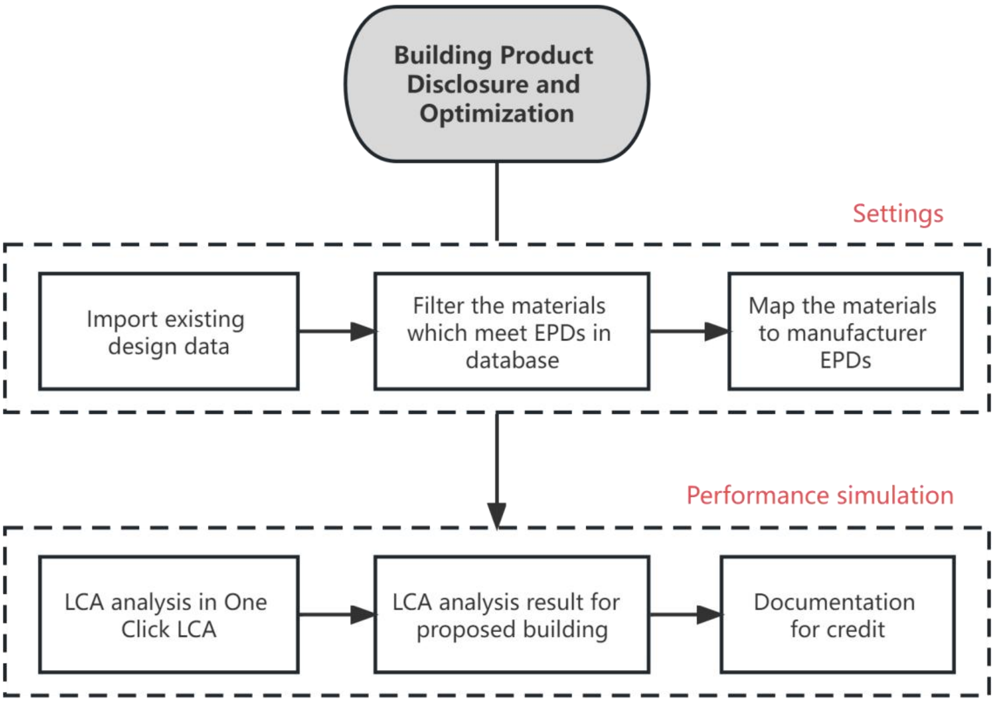


Figure 95. Workflow for the credit

The intent of the credit is to encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. The credit can be used to reward project teams for selecting products from manufacturers who have verified improved environmental life-cycle impacts.

The credit rewards the project which can use at least 20 different permanently installed products sourced from at least five different manufacturers that meet the Life-cycle assessment and environmental product declarations. In addition, the project needs to use at least 10 permanently installed products sourced from at least three different manufacturers which can demonstrate environmental impact reductions on the six impact categories mentioned in the last chapter.

For the project, the credit can also be achieved through the software One Click LCA since the platform includes all the world's EPD data. In the materials tab as Figure 96 shows, the materials can be mapped to manufacturer EPDs or generic EPDs. Figure 97 shows an example of the EPD information and environmental profile with impact categories of the material in One Click LCA database. The materials can meet the environmental product declarations and satisfy the requirements for the Leed® credit. As a result, with several materials under environmental product declarations applied to the project as Figure 98 shows, the project can achieve 2 points in this credit.

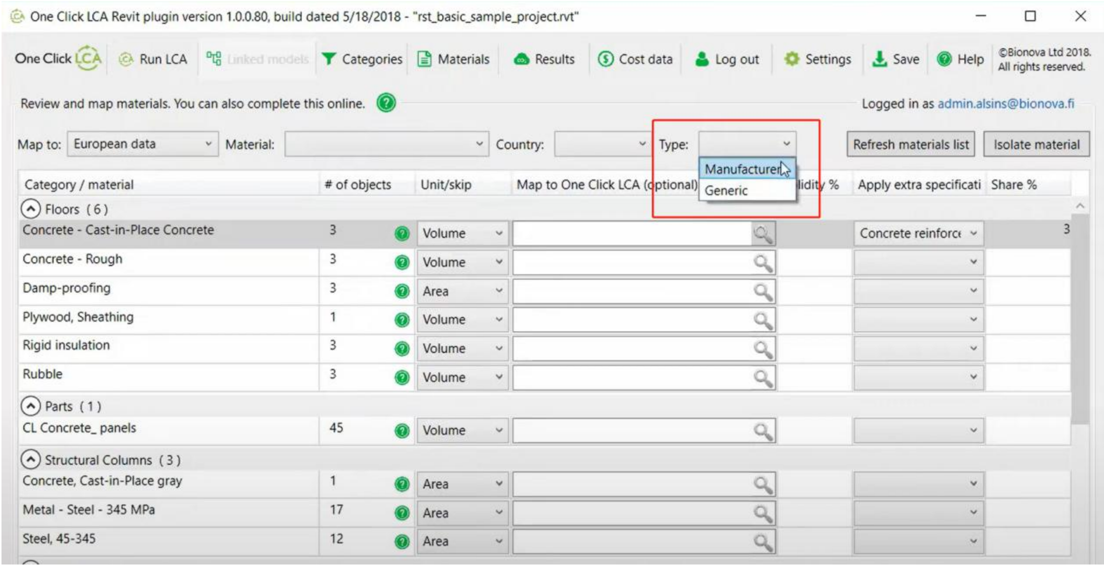


Figure 96. The materials tab for manufacturer EPDs

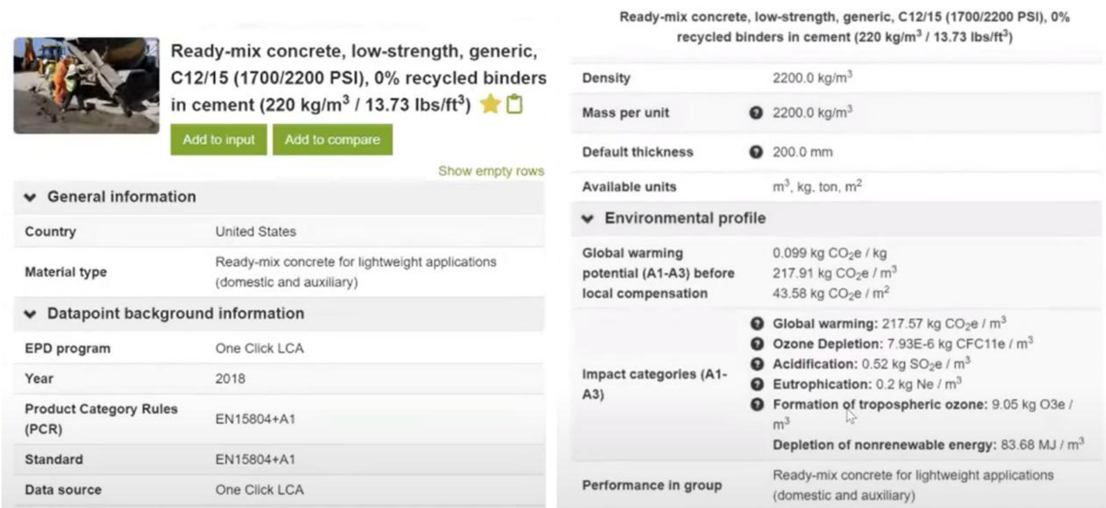


Figure 97. Environmental profile of the material in database

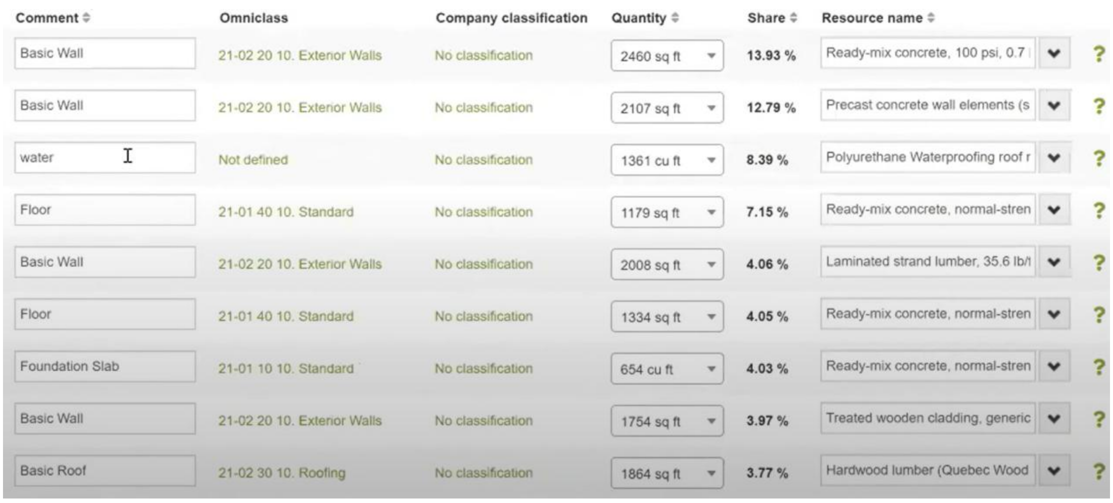


Figure 98. EPD materials apply to the project

In summary, through the assessment with the BIM-based performance simulation, 33 points in 5 credits from 3 categories can be evaluated and the project can achieve 27 points in total as Table 33 shows.

Table 33

Summary for the assessment with BIM-based performance simulation.

Category	Credit	Available points	Earned points
Prerequisite	Minimum Energy Performance	Required	Required
Indoor Environmental Quality	Daylight	3	2
Energy and Atmosphere	Optimize Energy Performance	18	14
Energy and Atmosphere	Renewable Energy	5	5
Materials and Resources	Building Life-Cycle Impact Reduction	5	4
Materials and Resources	Building Product Disclosure and Optimization - Environmental Product Declarations	2	2
Assessment with BIM-based performance simulation		33	27

6.4 Additional Points from LEED® Rating Systems

6.4.1 IP Credit: Integrative Process

The intent of the credit is to support high-performance, cost-effective project outcomes through an early analysis of the interrelationships among systems.

The credit rewards the project which identifies and uses opportunities to achieve synergies across disciplines and building systems in pre-design and continues throughout the design phases. The analysis need to consist of energy-related system which is about energy modeling analysis, and water-related system which is about performing a preliminary water budget analysis.

Since in the thesis work, BIM can work on performing energy use analysis, lighting analysis and indoor water demand analysis of the building which is a comprehensive analysis across disciplines and building systems, the project can achieve 1 point in this credit.

6.4.2 RP Credit: Regional Priority

The intent of the credit is to provide an incentive for the achievement of credits that address geographically specific environmental, social equity, and public health priorities.

Each site has six Regional Priority credits and each project can be awarded to four of the six credits. These credits have been identified by the USGBC regional councils and chapters as having additional regional importance for the project's region. A database of Regional Priority credits and their geographic applicability is available on the USGBC website: http://www.usgbc.org.

In the website, the site can be set and the version and type of building can be chosen. In Figure 99, the four Regional Priority credits for the project which have already been achieved through BIM are Reduced parking footprint, Electric vehicles, Indoor water use reduction and Daylight. Therefore, the project can achieve 4 points in this credit.

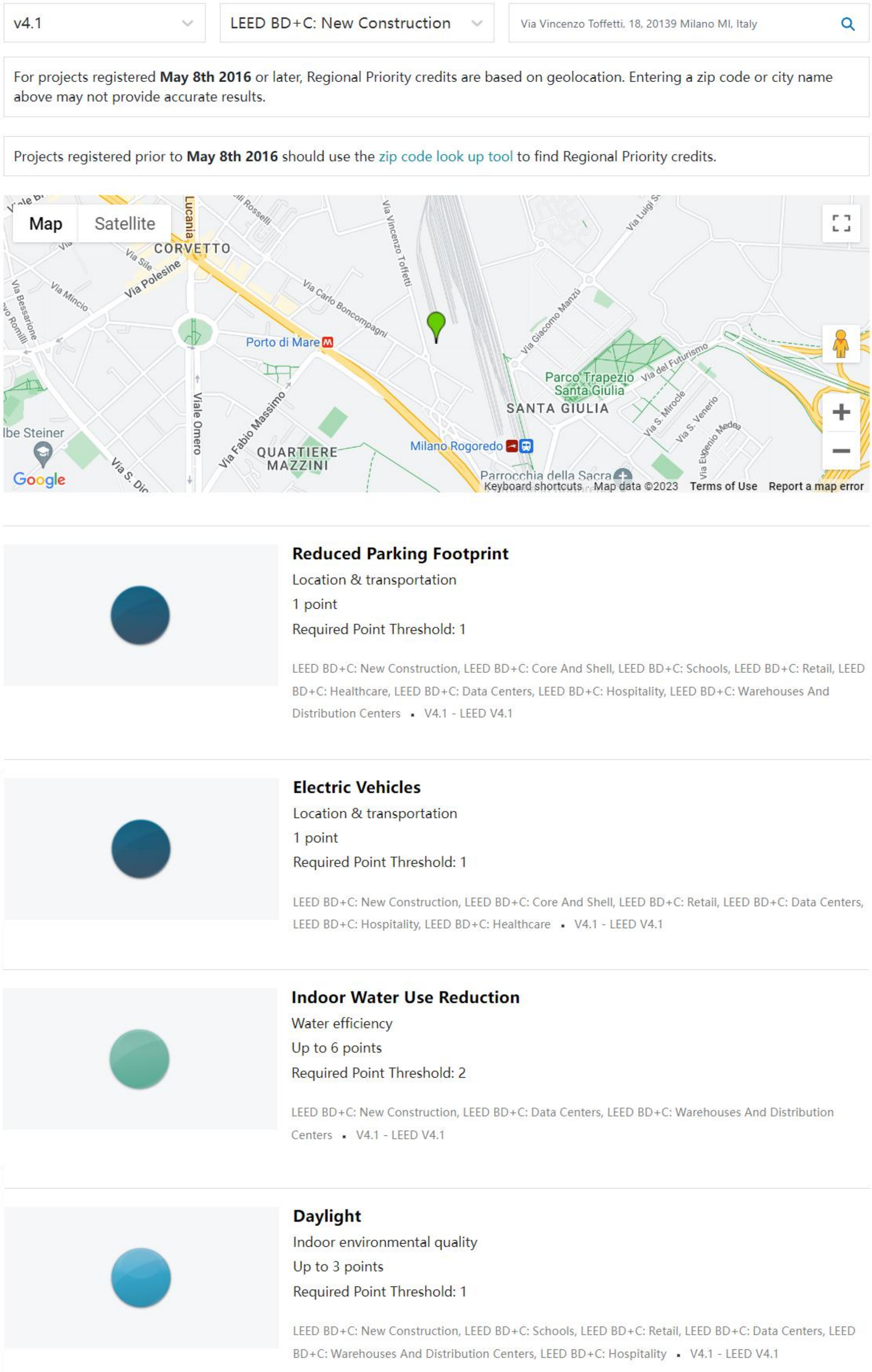


Figure 99. Website for Regional Priority credits of the project

In summary, through the additional points from LEED® rating systems, 5 points in 2 credits from 2 categories can be evaluated and the project can achieve 5 points in total as Table 34 shows.

Table 34

Summary for the additional points from LEED® rating systems.

Category	Credit	Available points	Earned points
Integrative Process	Integrative Process	1	1
Regional Priority	Regional Priority	4	4
Additional points from LEED® rating systems		5	5

7 Conclusion and Future Research

The study presents a methodology of combining the advantages of BIM technology with green building information statistics, performance analysis and green building evaluation system in the design stage of construction projects. It takes a student residence in Milan as a case to valid the use of BIM technology in the sustainable design and LEED® certification process. The conclusions can be drawn from this research study as follows.

1. The proposed BIM-based approach is efficient. The practicality of the constructed BIM 3D model and BIM-related tools can easily carry out green building information statistics and performance simulation, and on this basis, evaluation and optimization can be effectively realized. Furthermore, the proposed method can effectively incorporate the required rating system into green building assessment. As presented in the case study, the LEED® rating system is incorporated into the assessment of student residence design in Milan. The study combines the application characteristics of BIM technology in green building design and sorts out the application points of assisting green building evaluation based on BIM technology.

2. The results of BIM-based applications and sustainability analyses software can be used to directly or semi-directly generate LEED® documentation. Up to 61 LEED® credits and 2 prerequisites can be documented using results generated by BIM-based software as shown in Table 35.

3. BIM-based sustainability software can produce results very quickly and automatically compared to traditional manual methods. In other words, building information models can serve as the basis for running these analyses. This saves a lot of time and resources.

4. The characteristics of BIM technology make it widely used in the green building design stage. Using BIM design can simulate the environment around the project, and inputting the location, climate, daylight, and material information of the project can achieve a simulation result that is closer to reality. By connecting with external green building simulation software, the work efficiency of green building performance simulation can be improved and the consistency of the design model and the simulation model can be ensured, which reflects the advantages of BIM technology in information management in green building design.

Limitations exist in this research. The aim of this study is to propose a method that can be effectively applied on a wide scale. Although the case study demonstrated the applicability of the proposed approach, only the LEED® assessment criteria is included in the green building assessment due to limited available data. One of the future works is to evaluate and optimize green buildings according to different criteria to test their suitability and effectiveness.

Besides, there are many types of green buildings with great differences. Considering the time and depth of research, the study only selected the residential projects which is the most popular in green buildings for in-depth and systematic research, without studying other types of green buildings or different geographical regions. In future research, the research boundaries can be further expanded and the research on the application value of BIM in sustainable designs of different types and regions can be gradually enriched.

The study is based on the application of BIM technology in the analysis of sustainable design in the design stage. Further research is needed on the wider use of project data established by BIM in the future and the current obstacles to the widespread application of BIM in sustainable design, so that the project database established through BIM technology can play a role in all stages of the construction, and can also create a new design-construction-operation model to achieve greater value.

Table 35

Summary of the LEED® credits earned using BIM.

Category	Credit	Available points	Earned points
Prerequisite	Indoor Water Use Reduction	Required	Required
	Minimum Energy Performance	Required	Required
Assessing through BIM-based statistics and calculation	Surrounding Density and Diverse Uses	5	5
	Access to Quality Transit	5	5
	Bicycle Facilities	1	1
	Reduced Parking Footprint	1	1
	Electric Vehicles	1	1
	Open Space	1	1
	Heat Island Reduction	2	2
	Indoor Water Use Reduction	6	4
	Quality Views	1	1
Assessing through BIM-based performance simulation	Daylight	3	2
	Optimize Energy Performance	18	14
	Renewable Energy	5	5
	Building Life-Cycle Impact Reduction	5	4
	Building Product Disclosure and Optimization - Environmental Product Declarations	2	2
Additions	Integrative Process	1	1
	Regional Priority	4	4
Total points earned using BIM		61	53

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