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A BIM-Based Tool for Assessing Sustainability in Buildings Using the Green Pyramid Rating System

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Abstract: Green construction management is an approach that aims to promote sustainable solutions in building design and construction. However, the complexity and variability in design scenarios often pose challenges to implementing these practices effectively. This study proposes a collaborative framework for green construction management that leverages automated and semi-automated simulations to facilitate performance-based decision making. The framework utilizes the green pyramid rating system (GPRS) as a third-party certification assessment provider. It employs various BIM analysis software tools, including Dynamo codes in Autodesk Revit and add-in plug-ins using Revit API, to extract information and parameters from the BIM model. The data are used to perform quantitative calculations and comprehensive analysis that aid decision makers in investigating, analyzing, improving, and assessing sustainability aspects throughout the project. The proposed framework enables a structured approach to green construction management that incorporates the building variable consecutive level of details/development (LOD) and life cycle phases. A case study of an office building in the new administrative capital in Egypt demonstrates the effectiveness of the framework in promoting sustainable solutions. The collaborative framework for interoperability design decisions proposed in this study provides a valuable tool for implementing green construction management practices. The use of automated and semi-automated simulations, following the GPRS, helps to ensure that sustainable solutions are advocated, interrogated, and refined throughout the project. The framework's structured approach enables decision makers to investigate, analyze, improve, and assess sustainability aspects effectively.

Keywords: sustainability; construction projects assessment; design phase; building information modeling; green pyramids rating system

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1. Introduction

For the past decades, awareness of the earth and the environmental situation was not considered an important issue until the late 20th century, when technology and industry, in addition to the growing population, were negatively affecting everything around them. This environmental impact will significantly affect all following generations, particularly in developing countries. Therefore, innovative ideas, principles, and studies between dedicated professional roles (e.g., environmentalists, architects, ecologists, etc.) introduce new ideologies to develop technologies aiming to compensate for the adverse impact of fast-growing developments to achieve sustainable solutions through collaboration and beneficial decision making. Hence, throughout history, information has been developed to involve new sustainable methodologies to assess previous work results, assign new practices and techniques to raise the influence of sustainability momentum, and increase awareness of the best environmental practices through different advent technologies [1]. Green construction requires and suppresses information and data to support, identify, and review the negative impacts a project can be exposed to, such as waste, energy consumption, or pollution, through continuous development efforts to support the sustainability approaches and environmental aspects.

The construction industry significantly affects the environment; it is considered a paramount reason behind energy use, water waste, waste generation forming landfills, the destruction of habitats, unpleasant health conditions, and many other negative impacts. Thus, according to the UN Environment Program (UNEP), construction is responsible for enormous burdens and various effects, 36% of energy consumption, 37% of all energy-related CO_2 emissions, and 40% of solid wastes through construction and demolition, in addition, to consuming almost 12% of global water usage [2]. Not only does construction affect the environment but it also directly impacts human health, productivity, and efficiency because of the indoor environment and materials used. Hence, professionals encourage using new building technologies integrated with standards and policies; the vital concepts introduced to practically apply the vision of saving the environment. Furthermore, developing strategies such as green buildings, smart cities, and environmental were introduced to lessen the negative impact of the building sectors by many means such as using energy utilizing conservation tools, energy performance systems, and renewable energies [3]. For example, new building technology approaches to sustainable development goals might require developing cities through green construction, sustainable design approaches, and reducing the consumption of scarce resources to lessen and manage waste [4]. In addition, social goals rely more on human comfort and health through better indoor environmental qualities to reduce negative impacts and to create a good living or working environment within the building.

Adopting superimposed methodologies is imperative for Egypt to curb negative environmental impacts and build a sustainable living environment that respects human health. This research aims to shift toward sustainable and green buildings in Egypt through a local rating system and promote efficient energy, resource, water, and indoor environmental quality. It also aims to develop a framework that integrates BIM and the local Egyptian sustainability rating system to assess sustainability in construction projects at the early design stages. The scalable methodology aims to bridge the gap in implementing new technologies and work methods leading to Egypt's low-carbon, highly efficient, and greener buildings. The research includes developing a dynamic BIM tool incorporating sustainability aspects and using simulation tools to enhance performance and meet the green pyramid rating system (GPRS) credits. A Revit API plug-in Sustainable "GPRS BIM-based Tool" is also introduced to automate sustainability assessment and specify the achieved certification level.

2. Literature Review

2.1. BIM Tools for Sustainability Assessments

Green building design remains a complex task that requires the adoption of the integrated design process (IDP), where BIM can be used to improve decision making in building design. An elementary means of using BIM to improve decision making is to reduce the work involved in evaluating multiple options early in the design process and save time [5]. Information management uses building information modeling through the ISO 19650-1 [6] series title, which generalizes information requirements processes since sustainable building assessment requires information exchange from various building professionals. Pikas et al. [7] further argued that there is a general lack of theory on building design where the model information can be exchanged between various software tools. In contrast, data interoperability is the ability to exchange and use information. The model information is combined with the model buildings to design and use the various inputs to simulate and analyze the building performance and different types of consumption, including energy, water, and others [8]. The various analyses use the latest software technologies such as ArcGIS, EnergyPlus, and Insight by effectively sharing models within the OpenBIM-facilitated common data environment (CDE) and quickly prioritizing and identifying the interoperability of different sustainability tools to gain an overall environmental assessment [9]. The CDE may follow the standards that are assessed to develop the methodology of the sustainability approach in the ACE industry for construction environmental impact assessment (EIA) through the environmental product declaration (EPD) and other considerations [10].

BIM-enabled 6D sustainability analysis can also assist in identifying potential risks and issues that may arise during the operational phase of the building, allowing for proactive measures to be taken to avoid or mitigate these risks. Additionally, it can help in the decision-making process for retrofitting or refurbishing existing buildings to improve their sustainability performance. By simulating various scenarios and analyzing their potential impact, stakeholders can make informed decisions to optimize the sustainability of the building while minimizing the associated costs. BIM 6D simulation is essential for construction projects' sustainability assessment and appraisal processes. For instance, the main objective of "The Energy Performance of Buildings Directive" from 2021 is to require all buildings to be nearly zero-energy buildings (NZEB) [11]. To mitigate these impacts, the BIM process uses the digital interconnectivity between various BIM software for the needed actions since one software does not perform all of the requirements. BIM software and the wide range of functions for different BIM solutions with brief descriptions assist in choosing the right BIM software, which can be challenging, especially since various sustainability-related practices and measures are being introduced [12]. In addition, multiple constraints influence software choices, such as price, capabilities, and interoperability requirements. Additionally, through BIM, the user can rapidly test numerous options of varying complexity and quantify and test variable productivity and efficiency due to better communication and integration, accelerating the project timelines [13].

2.2. Development of Green Building Rating Tools

Green building rating tools (GBRT) or green building assessment tools (GBATs) are established as sustainability metrics for assessing green building design. Green building environmental rating systems (GBCs) are different worldwide; thus, they have similar structures through different levels of detail in evaluating buildings according to various approaches and categories such as the site, energy consumption, water efficiency, material use, indoor environment, and innovative solutions. Moreover, GBCs significantly aim to reduce energy, carbon, and water consumption, raw materials, and waste production. There are various GBCs for the construction industry; for instance, the most popular rating system is leadership in energy and environmental design (LEED), building research establishment environmental assessment methodology (BREEAM), Energy Star, Well, Green Globes and German sustainable building council (DGNB) [14]. Examples of middle east green rating systems include the green pyramid rating system (GPRS) in Egypt, the global sustainability assessment system (GSAS) in Qatar, the pearl rating system (PRS) in UAE, and the ARZ building rating system in Lebanon [15].

On the other hand, many initiatives have sought procedures to obtain comfortable buildings using various sustainable building rating systems as assessment tools to examine the expected performance of the whole building and translate that into an overall assessment that allows comparing the building against the regulated benchmarks or the other facilities [16]. However, there are a lot of "Voluntary Green Tools" to explore and analyze the building according to the needed function, such as frameworks, checklists, rating, ranking tools, analytical tools, various software with expert systems, and organizing tools [17]. Although there are numerous methods for assessing the sustainability performance of a building, the green building assessment method developed by LEED is the most popular used worldwide due to its comprehensiveness and simplicity. Thus, countries must develop rating systems based on local standards to assess their sustainable construction practices and reach sustainable design aims [18]. Despite the numerous contributions toward a sustainable built environment, as shown by the abovementioned green building assessment tools, each country believed that the examined certification systems needed strong adaptation to meet the needs of the local climate, social, cultural, environmental, and economic conditions [19]. The GPRS is an Egyptian rating system that aids in assessing sustainable construction practices and achieves sustainable design aims. It captures the local context of Egypt and its national priorities. The GPRS is developed with the specific goal of ensuring that sustainability assessments in Egypt accurately reflect the country's unique context and priorities through different perspectives. It takes into consideration the specific environmental challenges that are present in Egypt, such as water scarcity, desertification, energy efficiency, and pollution, which are key environmental challenges in Egypt. GPRS also considers the urbanization challenges that Egypt is facing, such as rapid population growth, informal settlements, and pressure on natural resources. Therefore, the system encourages the development of green buildings in urban areas while promoting sustainable urban development toward desert areas since buildings consume significant amounts of natural resources during their lifespan. Implementing green and sustainable principles can help to reduce the negative impact of buildings on the environment and provide economic benefits throughout the building's lifecycle. Moreover, GPRS incorporates the national priorities outlined in Egypt's sustainable development strategy (SDS), also known as Egypt Vision 2030. The SDS goals related to the environment, energy, and urban development are specifically addressed by the GPRS certification levels, which provide a practical framework for building owners, designers, and governmental authorities to collaborate and achieve sustainability.

The GPRS assesses buildings using seven main qualitative categories to address the contents and dimensions. These categories are sustainable site (SS), energy efficiency (EE), water efficiency (WE), materials and resources (MR), indoor environmental quality (EQ), management protocols (MP), and innovation and added value (IN). The scoring system is a quantitative weighted score to calibrate building performance and determine the compliance control status. The summation of the collected points is 100% points, in addition to a 5% bonus. The GPRS certification levels are credit-based to control the rating process and determine the building certification and level of rating; up to five green pyramids can be awarded for sustainability. The certification levels are Platinum (greater than 80%)—five pyramids, Gold (65–85%)—four pyramids, Silver (50–60%)—three pyramids, Bronze (50–40%)—two pyramids, and Certified (40–30%)—one pyramid. Several research efforts have been made to analyze GPRS.

The GPRS needs to be designed and implemented with an integrated approach that uses a systematic process that includes stakeholders from all levels of society (e.g., policymakers, decision makers, designers, and contractors). Moreover, the government should empower and encourage the GPRS policy at the federal level to ensure consistency and then integrate these standards into the urban planning laws of the cities. This approach helps promote incorporating green design principles, sustainable building practices, and technology into construction planning and operations in urban areas of Egypt. On the other hand, the authors examined various aspects of building sustainability and rating systems and explained different BIM-based building information modeling (BIM) frameworks and sustainability approaches.

For instance, Edeisy and Cecere [20] presented a study on developing the current building energy efficiency code (BEEC) to consider the gaps, needs, and requirements by providing guidelines that help increase energy efficiency in the residential sector in Egypt in addition to developing training to provide the teams with technical knowledge and required skills of the current code compliance. Younan [21] conducted a comparative study, comparing different rating systems to construct a new rating system that fulfills the Egyptian construction sector requirements. Karmany [22] compared three rating systems (LEED, GPRS, and TARSHEED) to identify which is more applicable in Egypt and highlighted that gaps should be considered in future versions of the assessment system and should follow the technical knowledge and the country's local strategies and needs. Mohamed [23] recommended developing a roadmap to mandate BIM in the Egyptian construction industry and develop BIM best practices and implementation process platforms. Hazem et al. [24]

introduced a sustainability research roadmap and proposed a new energy rating system for new and existing buildings.

Hazem and Fahmi's [25] study also introduced a new rating system for new construction in Egypt, addressing all categories using the AHP as a step toward implementing green concepts. Attia and Dabaieh [26] adopted a dual mixed approach to ensure the importance of developing the GPRS certification rating system to meet the climate, social, cultural, environmental, and economic needs according to the local conditions, and adapt them to the local construction practices. Meanwhile, Ammar et al. [27] mentioned that GPRS still needs more development and improvement, although GPRS was developed based on the international US LEED. Moreover, it is essential to develop the system as an idea that incorporates all project participants by integrating architectural, constructional, electrical, and mechanical with environmental experts from the pre-design and design stages through the construction, processing, and maintenance phases. On the other hand, Cascone [28] examined the potential integration between LEED and BIM. Various integration techniques, such as third-party software data exchange, cloud-BIM, and plug-in development through API, were analyzed for their applicability in the early design phase. Additionally, BIM Toolkit [29] was introduced as a UK-initiated part of the Level 2 BIM package of tools and standards. Thus, the main challenge for implementing sustainable construction in Egypt and developing improved green building certification systems is encompassing critical green building sustainability criteria that can be used to validate the actual credits assessable with BIM technologies and minimize the gap between simulation outputs from analysis tools and real-world values [30]. However, the construction industry in Egypt is lagging in adopting new technologies aiming to improve the quality of construction [31].

2.3. Research Gap

The proposed approach has identified several research gaps that need to be addressed, challenges related to GPRS sustainability assessment issues, and the development of an indicator tool. These areas include the need for a better understanding of the integrated project delivery method and sustainability assessments, a dependency on international frameworks and methodologies, the lack of integration between BIM technology and GPRS guidelines, the absence of decision-making criteria for engaging BIM methodologies and sustainability rating systems, and the absence of an intuitive interface to incorporate more advanced sustainability criteria into the decision model. Addressing these research gaps and challenges is critical for making the building certification process more accurate from the design's early stages and improving sustainability assessments in the construction industry.

3. Proposed Framework

The research proposes a framework to illustrate the feasibility of construction projects using BIM for sustainability rating analysis in the design and construction to assist the building industry in improving its environmental performance. The framework utilizes automated BIM-authorized tools and a developed Revit API plug-in to contribute to disseminating sustainable construction. These tools allow multidisciplinary information integration for faster, more accurate, and more efficient sustainability evaluation and analyze and simulate energy performance results to obtain alternative design options. Furthermore, the framework acts as a sustainability decision-making support tool in a collaborative platform to achieve better sustainable buildings by ranking the sustainability certification level based on the various physical features, performance assessments, and calculations of the combined results from the different categories of the proposed design of any building typology. The assessment is carried out according to the GPRS local sustainability rating systems. As such, a building can be classified as Denied, Certified, Bronze, Silver, Gold, or Platinum.

The proposed framework identifies a roadmap to introduce GPRS integrated with the latest BIM technologies and tools for building assessment within Egypt through a comprehensive screening of the initial effects of sustainability factors. The framework builds a relationship between the green building rating processes and integration functionalities of BIM. The adopted methodology corporates the design processes to pursue the certification and achieve the ideal design solutions according to specific principles and fundamentals that need to be examined to adopt the green building approach and needs. The stages depend on the efficient coordination of people, tools, and technology as sustainability pillars combined with the BIM pillars of policy, process, and technology.

Figure 1 illustrates the methodology adopted for this study, which includes several stages. In the first stage, the project brief, goals, information, and requirements are studied and defined, and the available information and data are analyzed, checked, and documented. The second stage involves preparing the fundamental design and sustainability modeling requirements using BIM authoring tools. This is followed by using BIM simulation tools to assess the sustainability of the design, which can be divided into assessment sustainability tools and rating sustainability tools. The assessment tools develop several configurations of passive and active systems that can be applied to the building. These tools help each profession choose the most applicable option from various alternatives. The rating tools, on the other hand, assess the environmental impacts of the building design based on specific guidelines or systems. The goal is to ensure that the environmental impacts are assessed and that the building design achieves a certain level of sustainability. This study incorporates technology to create a Revit plug-in as a sustainability BIM rating tool to achieve higher compatibility. The tool evaluates the sustainability of the proposed building based on the GPRS-collected scores. According to the GPRS sustainability certification levels, the calculated total score determines the sustainability certification level of the building model, which can range from Denied, Certified to Bronze, Silver, Gold, or Platinum.

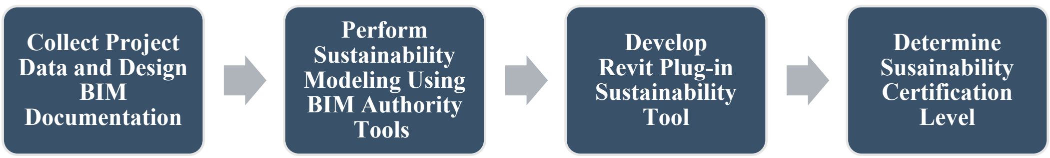

Figure 1. Proposed Framework Development Stages.

It is essential to define the requirements and establish communication through a detailed planning guide to establish the BIM implementation plan. This guide identifies the BIM goals and includes each stage's required uses. The BIM execution process is then designed to include tasks, information delivery strategies, and information delivery milestones. Additionally, the BIM deliverables are defined to develop the information protocol, the responsibility matrix, and the level of information needed for each BIM use. This framework is based on integrated project delivery (IPD) principles, requiring advanced BIM capabilities from all project team members to facilitate, implement, and review the BIM use process correctly.

It is crucial to communicate the LOD requirements to all project team members to ensure that the models are appropriate for the intended use and contain the necessary level of detail and accuracy. Management is explicitly acknowledged as a central component of the BIM methodology's success through proper planning and governance to establish and utilize the feedback loops to the appropriate stages. Therefore, the BIM implementation ranges from Level 1 to Level 3, depending on the level of information needed, which manages the project's lifecycle and expands toward asset management. Moreover, BIM management identifies the weaknesses in design and specifications to take proactive decisions from the beginning of the project and before construction. According to the explicit provisions on building performances, the users must acknowledge more innovative, powerful model authoring and analyzing tools to improve sustainable construction practices. The BIM application analysis with selected assessment certification allows the professional team to analyze each criterion and credit for the certification process.

Following these framework steps, competent construction planning decisions can be made before the construction begins.

3.1. Data Collection

The first step is to develop the green BIM decision process and create the necessary BIM documents for each project delivery stage. The team is built to determine the feasibility of achieving a GPRS certification level, and a general BIM execution plan (BEP) for the green BIM process map Level 1 is created. The data relevancy is elaborated, and potential BIM tools and software are determined to check the eligibility and efficiency for evaluating the building's performance. The project team's early involvement is necessary to perform an efficient IPD, and the RACI responsibility matrix chart defines each project team member's roles. The management and documentation start from the planning stage, as depicted in Figure 2. The design team determines the content, considers the client and other stakeholder requirements, and sets specific project green building targets and performance measures using GPRS credits and points. Data preparation, acquisition, and documentation are also carried out to clarify the project's scope and provide comprehensive information. Design development manages the gathered information data and prioritizes the goal of fulfilling the needed credit requirements to achieve certification. An assessment database is created and updated dynamically to include information related to green specifications, technical information, materials, and manufacturers. Finally, the team implements the system and submits all necessary documents for certification review and approval to verify the GPRS Checklist, ensure the credits are implemented, and report on the project's progress.

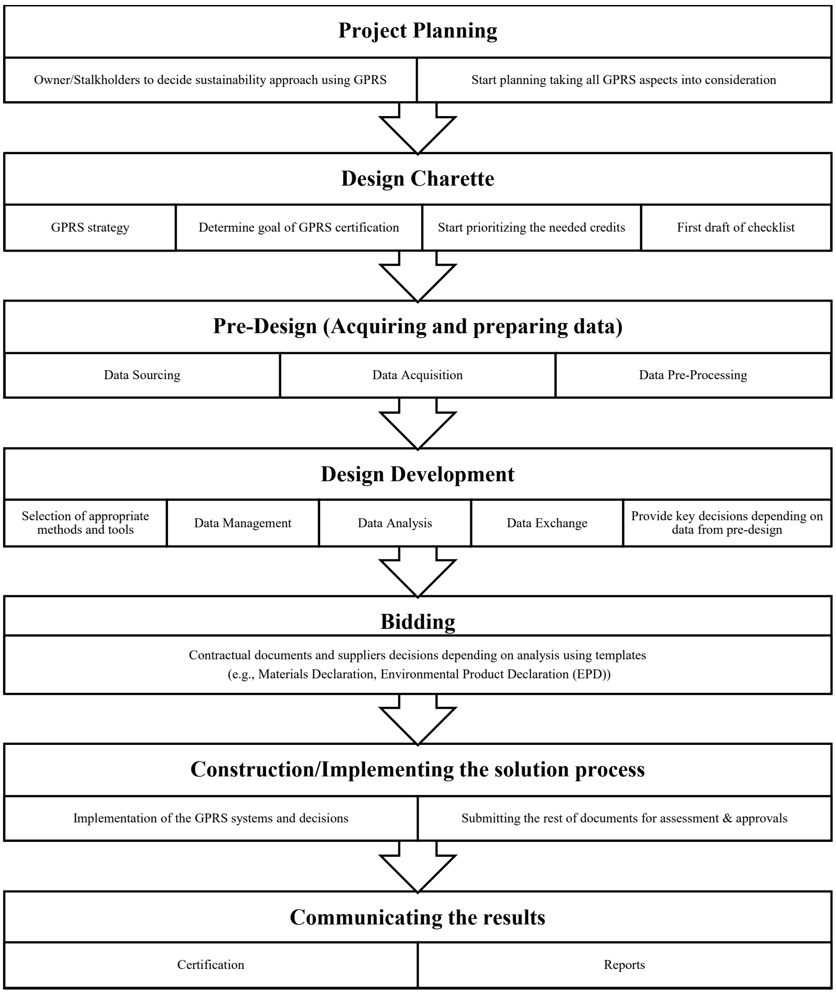

Figure 2. Management and documentation workflow.

3.2. Digitalize Sustainability Using BIM

The second stage of the BIM sustainability process involves the physical implementation of the BIM using a sustainability evaluation as one of its uses. Custom-made families with shared parameters are developed to create a logical flow of related data and provide architects, designers, environmental specialists, and the rest of the team with different building elements and components to assess decision making in the design development process. An external BIM database is created for sustainable materials, which is continuously updated with new innovative materials and specifications. The parametric Revit template and schedules ensure efficient management and improve interoperability for any project delivery method. The created parameters may be updated or modified, and new parameters may be added as needed during the sustainable design phase.

3.3. Model Development

The data extraction according to the interoperability characteristics and enhancements is vital in this step because the users directly link the BIM model to the external database. According to the extracted data from the previous results, the user constitutes the BIM-based model for implementing the proposed building to form a 3D model using a digital BIM authority tool for each constructional element. This is carried out to identify the current building geometrical situation and establish a baseline building mass and volume for the proposed design. The visualization model during the design phase provides better communication because of the improved demonstration of building function. Thus, it helps analyze the building forms and provides several design iterations to choose the most applicable design option. The user uses the available information such as spatial data (3D, site surveys, and site analysis), technical drawings (2D), unstructured data (text), and structured data (databases, spreadsheets). Then, a developed federated BIM model links all external disciplines such as architectural, structural, mechanical, electrical, and other system models overlaid to check interferences and conflicts within the building with the correct naming convention.

Firstly, the preliminary data required are the project information and physical properties. Then, the user inputs all of the properties of the objects to incorporate the information into the model before starting the modeling phase using Autodesk Revit. Next, the geographical location of the building is defined by the 'Internet Mapping Service' and provides the project site's exact location and the nearest weather station. In addition, spaces and rooms should have a defined name associated with their area and volume. Finally, the created space defines the initial room functions, zones, and activities for the first step of proper energy calculations after creating the model configuration.

3.4. Conduct Simulation Using BIM

In this building sustainability analysis stage, the user identifies and selects the list of sustainability indicators assigned to each sustainability category. Data exchange and synthesis of information files are the most critical interoperability factors between the various BIM applications and analysis programs to review the selection of techniques and processes for sustainable solutions. The correct information is key to gauging the valuable contribution of each criterion, ensuring the consistency of the best practical environmental options, and evaluating the sustainability performance of a building. First, the environmental baseline for a pre-assessment simulation is conducted to quantify the different environmental impacts for the whole building on the chosen project site location. Then, these performance model simulations test the retrofitting solution options while considering the study limitations to determine the base analytical models and the potential savings or improvements.

The overall workflow of the data analysis and simulation processes starts with importing the information of the created design specifications and GPRS database, as mentioned earlier, in addition to the specific information of the project as the input data. This is followed by the chosen BIM tools and software analysis from the early conceptual design phase, to conduct assumptions for various simulation options and incorporate the wide physical inputs such as building geometry and building orientation to select. Finally, each tool provides a detailed summary corresponding to its function based on new parameters created by the owners to assess the decisions for choosing sustainable materials. Then, different BIM energy modeling software and program needs are exported to provide different information, and file exchange tools and formats such as direct links between models, XML-based, IFC exchange formats, and proprietary and public file formats are used to transfer the output data and results seamlessly and efficiently. These data and calculations will help the decision makers to yield the desired project performance outcomes by changing some variables to meet the requirements of the targeted GPRS points.

3.5. Calculations and Schedules Generations

In this practice, the automatic extraction of specific data required from different databases and calculation tools is enabled to ensure a diverse visualization design for an easy user interface from the built-in parametric information in the form of comprehensive schedule views. The schedules are generated automatically based on the updated input information and may include building information, materials, components types such as room areas and volumes, detailed calculations, and materials takeoff schedules. The quantity takeoff data can be exported to a spreadsheet or an external database, or imported into another BIM tool. In addition, the schedules show the results of the calculations and can be exported in an Excel format for documentation and submission purposes. Dynamo is used automatically to generate, export, and import these data from/to the developed BIM model. The developed analysis system aims to optimize the building materials selection process. The components are customized and developed in the new GPRS BIM sustainability-based tool using the predefined GPRS families.

Figure 3 illustrates the output monitoring process for credit recheck after assuming how these factors will impact the building design and illustrates how to evaluate the project's compliance with the potential GPRS-collected points for each credit. In addition to comparing these alternative sustainable impact assessments and the steps, the data are extracted automatically for GPRS certification, documentation, and other enhancements. The building component selection criteria provide the designers with the required information related to the environmental criteria to reach green construction with various sustainable design options.

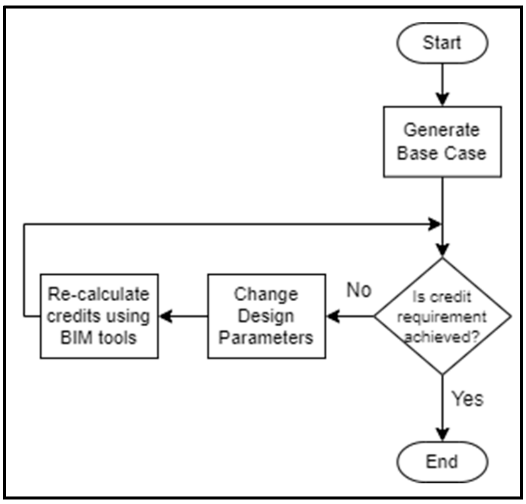

Figure 3. Proposed GPRS credit calculation process.

3.6. BIM Plug-In Development

The building sustainability assessment stage demonstrates practically the capabilities of seamless interoperability between the proposed GPRS BIM-based sustainability plug-in tool, developed in Autodesk Revit using a developed application programming interface (API). First, the user loads the plug-in into the BIM authority tool (Revit) with a graphical user interface (GUI). The tool uses the API to allow the user to extract the needed data directly and automatically from the BIM model. Then, the calculation formulas rely on integrating the input data from the user. The tool evaluates the indices, including the potential GPRS points that can be achieved. Even if the user changes the chosen materials or component scores as data input, the tool will automatically read the updated potential accumulated credits according to the category. The credit scoring systems acquire the needed sustainability parameters and then calculate the total potential sustainability final score. The integration extracts the weight factors for sustainability criteria from users and ranks the categories list of total potentially earned points for the project. This score is compared with the GPRS assessment standards and obtains the certification result. A summary report is generated to illustrate and detail the total points achieved for each category, and the sustainability certification level is certified as Bronze, Silver, Gold, or Platinum. The BIM-based tool assists the designers in modifying their designs from the early stage to adjust the estimated scores before submitting the documents for the final review. Even after exporting the result, it can be used for other purposes such as proof, documentation, design, and operations guidance.

The proposed framework provides several calculations and practical approaches through four significant steps to assess the sustainability level of the building according to the green pyramid rating system (GPRS) integrated with building information modeling (BIM). First, the sequence of the considered steps starts with providing and collecting project data and designing BIM documentation, then, using Revit as a BIM authority tool, the BIM model is developed. This is followed by performing sustainability modeling and conducting assessments using various BIM tools, methods, and technologies to provide a comparative analysis. As a result, the framework secures more accurate and consistent project information throughout the lifecycle compared with conventional management methods. In addition, it assesses selecting the most appropriate sustainable design solutions using energy efficiency approaches, determining better water-saving usage strategies, and choosing the most compatible materials for better green and sustainable constructive decisions after evaluating the performances and providing modifications. Thus, the process of developing this framework reduces the lack of accurate and adequate documentation by using the integrated information to combine BIM geometrics with the local GPRS sustainability guide while considering alternative design factors to support the decision makers through an organized BIM workflow. Finally, the developed plug-in includes a GUI that uses the API as a Revit plug-in, which allows users to automatically extract data from a BIM model and evaluate the potential sustainability of a building project. The plug-in includes calculation formulas to determine the building's sustainability level according to the GPRS.

The BIM is used to improve the contribution to sustainable development goals as many businesses are looking to move into greener buildings to reduce their negative environmental impacts. It also helps ensure that the building functions according to the design and sustainability requirements, and is intended to help achieve GPRS certification through a seamless workflow. This process involves verifying the results, documenting reports for other purposes, and creating a building that follows the best practices for sustainability while providing the latest updated information from project members and stakeholders. Procedures are proposed to incorporate the essential data and the needed information after the collection phase by applying different BIM applications for different categories, as shown in Table 1. For example, ArcGIS, Google Maps, and Autodesk Revit are used to assess the sustainable site category of the GPRS. The interoperability among the assessment tools is examined and achieved throughout the development process of the BIM Plug-in.

Table 1. Adopted BIM Tools for different green pyramid rating system (GPRS) categories.

Item	Credit	Max Points	Weight %	BIM Use	Assessment Method
Category 1: Sustainable Site (SS)					
SS.01	Site selection	12	3	Site Analysis/Existing Condition Modeling	ArcGIS/Google Maps/Autodesk Revit
SS.02	Community services and connectivity	8	2		
SS.03	Public transportation access and pedestrian access	8	2		
SS.04	Dedicated bicycle tracks and parking	4	1		
SS.05	Heat island effect	8	2		
Total		40	10		
Category 2: Energy Efficiency (EE)					
EE.01	Building envelope improvement	14	7	Energy Analysis	Autodesk Revit/Insight/Design Builder IESVE
EE.02	Passive heat gain reduction	10	5		
EE.03	Renewable energy sources	10	5		
EE.04	Energy-efficient HVAC systems	8	4	Mechanical Analysis	
EE.05	Efficient artificial lighting systems	8	4	Lighting Analysis	DIAlux
EE.06	Vertical transportation	6	3	Code Validation	N/A
Total		56	28		
Category 3: Water Efficiency (WE)					
WE.01	Wastewater reuse	20	10	Building Systems Analysis	Green Building Studio/Dynamo/Insight
WE.02	Water efficient landscape	10	5		
WE.03	Water efficient fixtures	20	10		
WE.04	Metering and leak detection system	10	5		
Total		60	30		
Category 4: Materials and Resources (MR)					
MR.01	Renewable materials and materials manufactured using renewable energy	4	2	N/A	N/A
MR.02	Regionally procured materials and products	6	3	Building Systems Analysis	Design Builder/One-click LCA
MR.03	Reduction of overall material use	8	4		
MR.04	Environment–friendly, sound, and thermal insulation materials	6	3	N/A	N/A
Total		16	8		
Category 5: Indoor Environmental Quality (EQ)					
IEQ.01	Enhance ventilation performance	8	4	Record Modeling/Building System Analysis	IESVE Design Builder EnergyPlus
IEQ.02	Smoking control	2	1		
IEQ.03	Thermal comfort	6	3		
IEQ.04	Visual comfort	4	2		
IEQ.05	Acoustic comfort	4	2		
Total		24	12		

Table 1. *Cont.*

Item	Credit	Max Points	Weight %	BIM Use	Assessment Method
			Category 6: Management Protocols (MP)		
MP.01	Building information modeling (BIM)	4	2	Overview Process Map/BIM Execution Planning	IESVE Design Builder EnergyPlus
MP.02	Life cycle assessment (LCA)	2	1		
MP.03	Building user guide (BUG)	4	2		
MP.04	Solid waste management	4	2		
MP.05	Building management system (BMS)	2	1		
Total		16	8		
			Category 7: Innovation and Added Value (IN)		
IN.01	Innovation and added value	10	5	N/A	N/A
Total		10	5		

The preparation and development of the various model factors (e.g., location, weather files, geometry, orientation, construction materials, thermal zones, occupancy operating schedules, and HVAC systems) are considered simulation baseline cases to analyze the first output data scenario for building operation using the preliminary building performance analysis. Then, the next step considers defining the potential improvements through various factors for each credit in the categories. Finally, the simulation retrofit scenarios through the deliberately limited input options comprise the building improvements. Using the performance-based approach, BEM may also be used as a decision support tool for better design decisions according to the building performance results, lifecycle cost, human comfort, and environment.

4. GPRS BIM-Based Tool Implementation

This framework implementation presents a case study to illustrate the proposed framework and the various BIM tools based on the different GPRS categories to utilize the potential project's issues and address the potential certification levels from the early stages. This research practically focuses on integrating BIM with GPRS sustainable modules in construction through a dynamic presentation and a BIM-based developed tool review. Furthermore, a case study model is conducted to allow efficient multidisciplinary project coordination following the principles of the GPRS to validate its requirements. Moreover, the case study highlights the intended sustainability goals to meet the needs of the parametric design, the performance-based evaluation analysis, and the optimization of the multiobjective design options to assist in decision making.

The preliminary design and construction consider the project's challenges and suggest solutions in addition to preparing the relevant documentation, drawings, calculations, photographs, and other essential details in the submittal formats that will eventually be submitted to the GPRS community. The project data should be recorded regularly through informative meetings with the environmental consultants to track the progress, detect actual needs, inspect site gaps, verify the credits, review documentation, and ensure that the project qualifications are on track. The team must also agree on which assessment rating tools to emerge in the preliminary and concept design to quickly assess the large-scale impacts of design alternatives and demonstrate how BIM-based energy analysis and design tools can support construction project teams in pursuit of GPRS certification for their projects.

Overall, a sustainability tool using the Autodesk Revit API for BIM-based formwork design and planning is developed. The tool provides a comprehensive rating system for sustainability metrics based on the GPRS categories and certification method at the BIM Stage 3 maturity level. The tool includes two steps to implement all of the required parameters for the GPRS. The first step is to create a family with credit names and points available for each credit of the seven categories and implement the various documentation types according to the data type. The second step is to group the newly created "Project Parameter" under the "Green Building Rating System (GPRS)" to create a schedule for each category with the parameters defined in step one. The values and quantities from the user input in Revit are extracted using an Excel spreadsheet to compare the different options. The final results are extracted using the Dynamo script and Python by advanced users to calculate the total using shared parameters. The script links the created parameters from the Revit model as input in the GPRS certification levels formulas to calculate the environmental values. Figure 4 illustrates the created Dynamo script for the developed BIM tool. Finally, the final certification level is released as the output to define the achieved certificate (Platinum, Gold, Silver, Bronze, Certified, or Denied) according to the established basis of the GPRS requirements interpretation and the BIM functionality screening from the previous steps.

The developed BIM tool is a user-friendly application to simplify the GPRS verification and certification procedure. C# is the programming language used to customize the design and development of the green building calculation BIM tool for certification assessment toward parametric design optimization. The tool integrates the information stored in a parametric BIM with building performance simulation tools, making it more accessible in the design process. This also provides a simplified way for the project management for the certification process, tailored in the BIM, to automatically generate the required documentation and streamline the application for certification. The tool appears as an add-in under a new tab called "IEDM" in Autodesk Revit's toolbar ribbon, where the plug-in's logo is designed in green-colored pyramids and is called the "GPRS Calculator", as shown in Figure 5. A pop-up window with a left tab containing the "General" and seven GPRS categories will appear. The "General" tab is the main window that is used to read the "Projects organization" and "Building Name" from the previously entered project information in the Revit model.

The proposed assessment tool checks compliance with the assigned credit maximum points to facilitate the data extraction process for GPRS automation assessment. This tool can also justify design decisions for the building and helps reduce significant barriers by eliminating the documentation process. The tool incorporates green building certification GPRS requirements at the project planning and design stage. As shown in Figure 6, the tool is designed to illustrate the credits of the seven categories of the GPRS, as well as a summary screen that shows the total. As such, the user can know the scorings for each category on the right, underneath the category logo. As the user selects a certain category, a new screen opens where the user can choose from the list of credits associated with that category. To validate the developed tool, each category uses the user's input from the created Revit's shared parameters and formulas for each credit to calculate and show results.

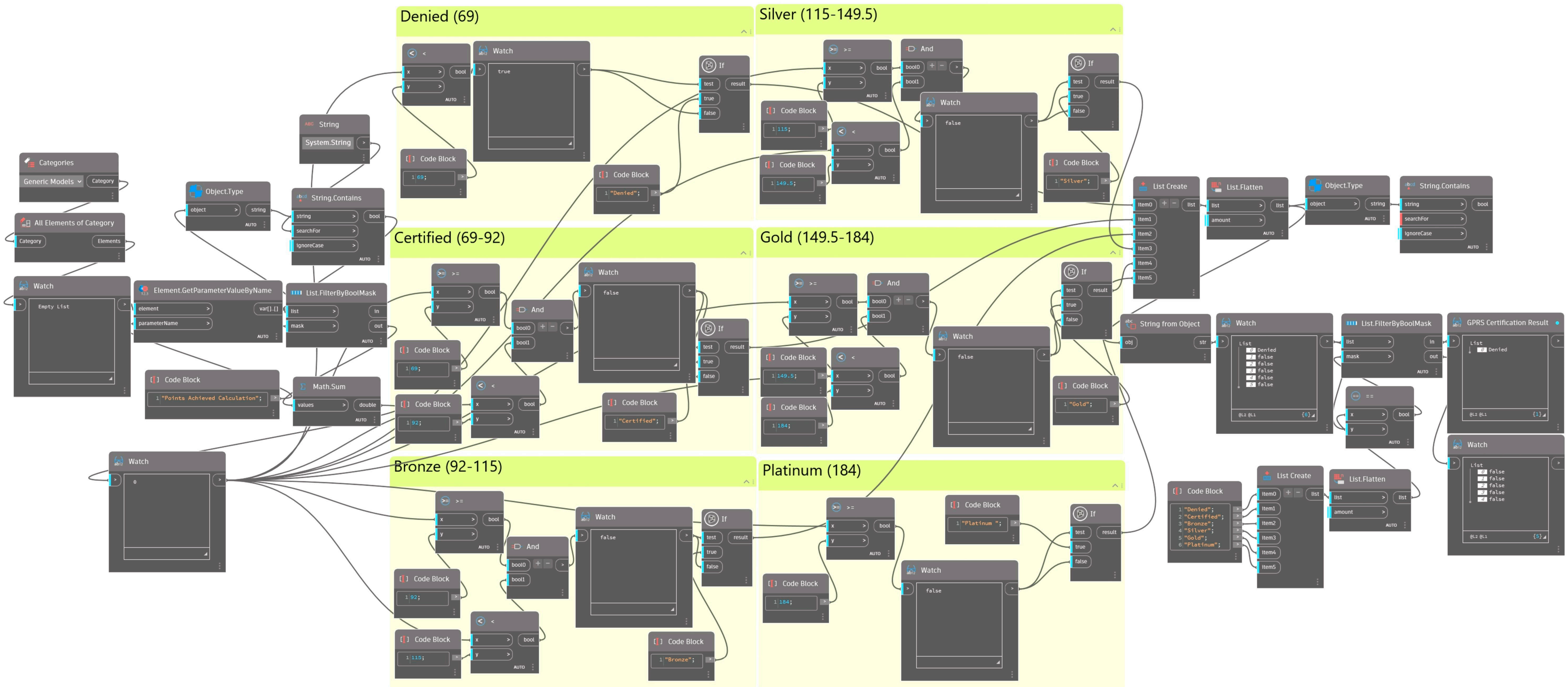

Figure 4. Dynamo script created for the developed BIM tool.

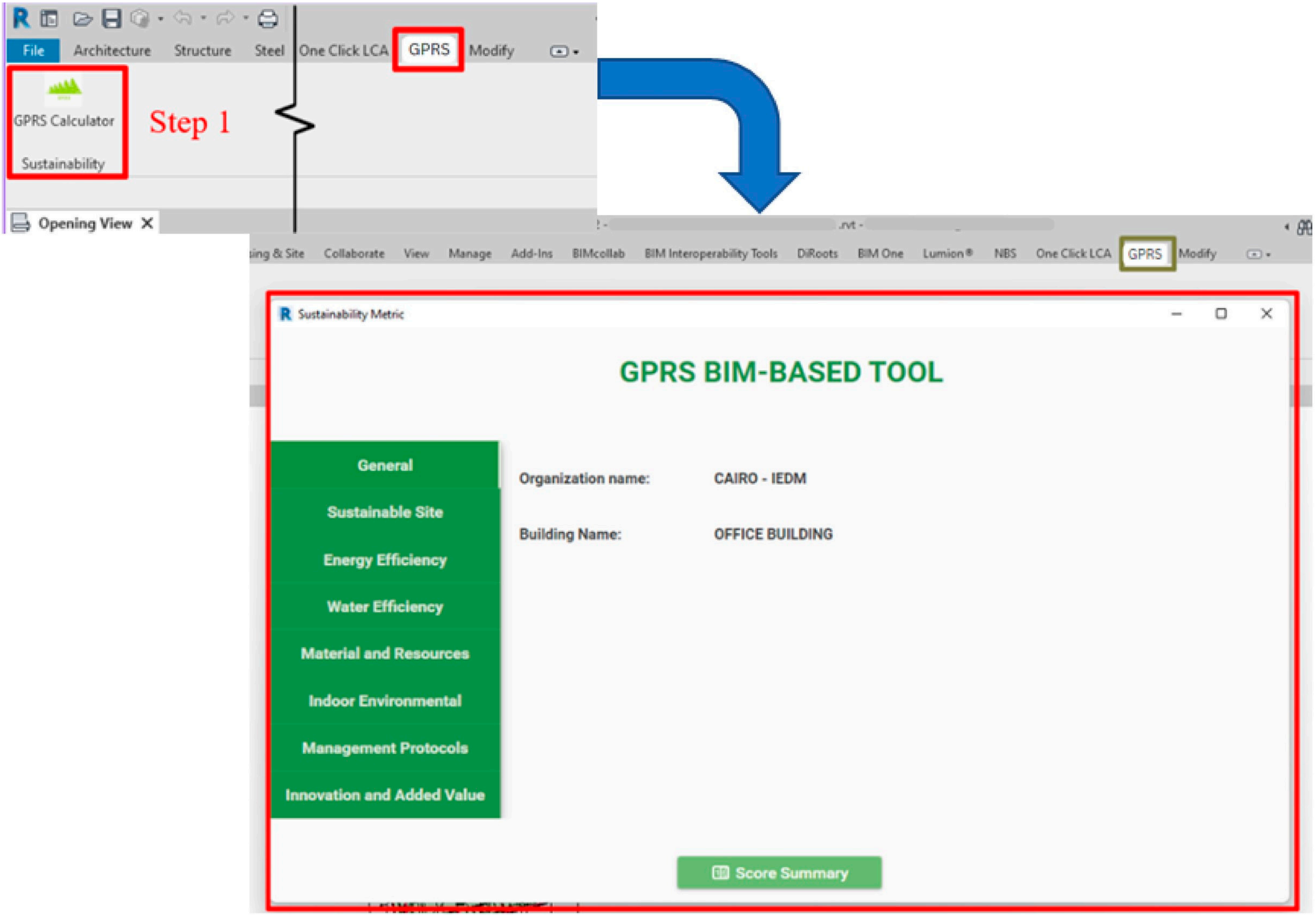

Figure 5. Proposed Revit API for the GPRS calculator user interface.

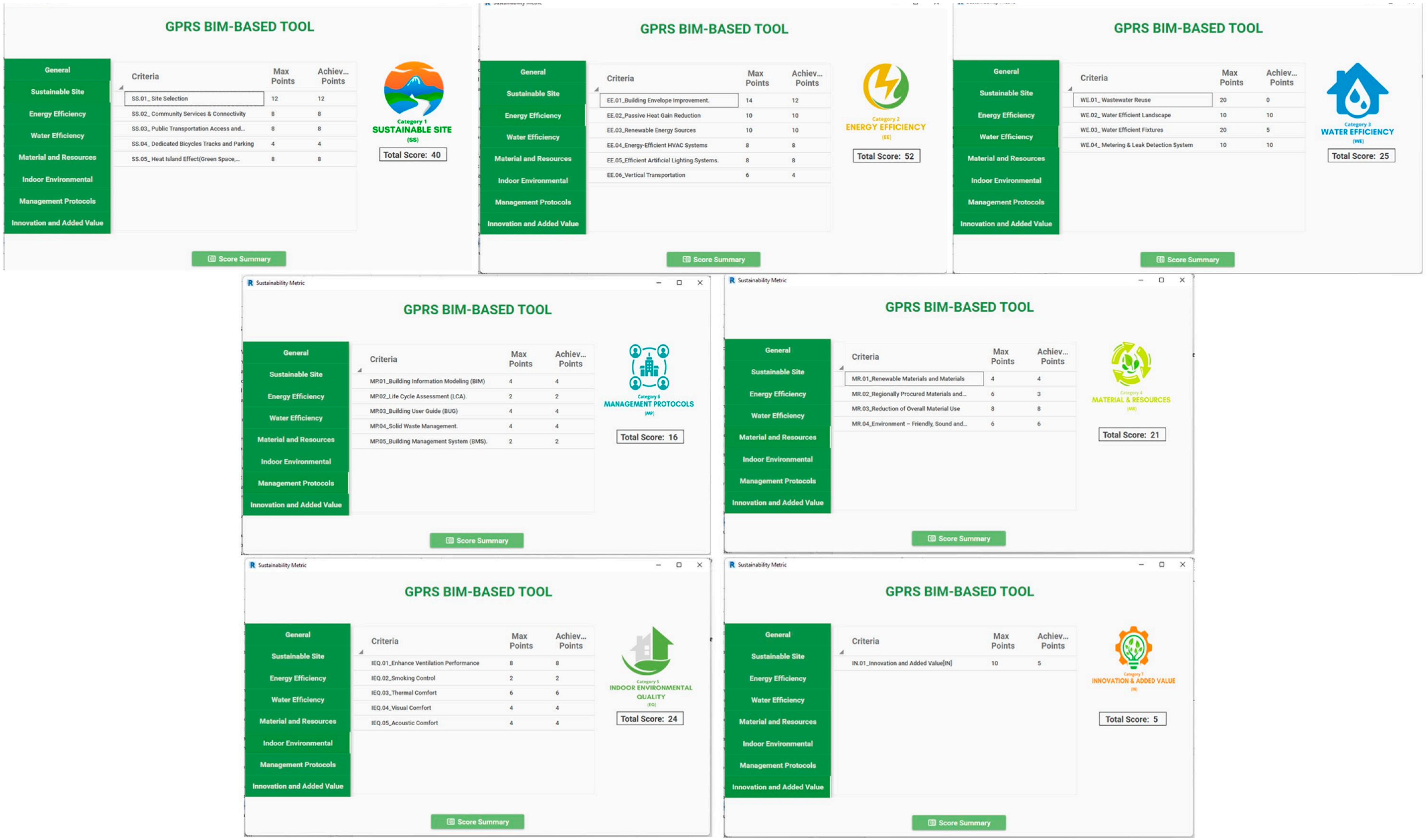

Figure 6. GPRS categories and credit score screens.

5. Case Study

5.1. Case Description

The case study considers a typical office building in the new administrative capital city urban area in Cairo, Egypt, which is considered a sustainable smart city model in urbanization and sustainability in Egypt. The main research objective is to benefit from the positives of green sustainable construction and propose alternative solutions for energy consumption and efficiency problems using the parametric-BIM modeling software. Several sustainability aspects demonstrate the benefits by linking various analysis results using simulation tools to capture detailed information about the environmental issues associated with the construction field. Furthermore, the study case explores the appropriate credits to meet the project, evaluates the performance of the building, and intends to achieve the GPRS certification for the office building. Finally, the 3D building models allow the users to understand the design potential visually. First, the project information provides further details for the design stage model to define the basic information and data, such as the owner of the project, the built-up area of approximately 9500 m^2, the number of floors, and the operation schedule, as listed in Table 2.

Table 2. Case Study Project's Main Information.

Owner:	SIAC Holding
Contractor:	SIAC Construction
Engineer:	Cosmos Engineering & Consultants
Project:	Office Building
Location:	New Capital
Built-Up Area:	Approx. (9500) m^2
Building Comprises:	2 Basement + Ground + 7 Typical Floors
Roof Area Opaque:	1590
Operation Schedule:	12 h/Day and 7 Days/Week
Target Certificate:	GOLD
Target Percent:	78.26%
Target Points:	180
Achieved Percent:	79.57%
Achieved Points:	183

Second, in the "Design Charette", the project team has to involve the owner and the other project stakeholders to define and clarify the BIM and sustainability expectations to fulfill the requirements and achieve the project's intent. Then, the team starts reviewing the checklists and the process maps and determines the desired level of certification to consider the credits and points needed, pursue the selected credits through various directions, such as environmental and financial perspectives, and then assign roles for each project team members accordingly after defining the project scope.

Table 3 shows the seven rating categories according to the GPRS national rating and certification schemes based on local regulations and standards. The determination of the maximum number of points and weight in % for credits is based on a set of criteria and subcriteria that are defined for each category of the rating system. These criteria are divided into several levels of priority, with higher priority criteria being assigned a higher number of points and weight in % for credits. The maximum number of points for each category is determined based on the potential impact of the category on sustainability.

For example, the energy efficiency (EE) category has a maximum of 56 points because the efficient use of energy is critical to achieving sustainability in buildings. Similarly, the sustainable site (SS) category has a maximum of 40 points because the proper site selection, orientation, and design can have a significant impact on the environmental performance of a building. The weight in % for credits in each category is determined based on the importance of the category in achieving sustainability. For example, the energy efficiency (EE) category has a credit weight of 28%, which is higher than any other category because it is critical to achieving sustainability in buildings. Similarly, the water efficiency (WE) category has a credit weight of 30% because water is a precious resource that needs to be conserved in buildings. The maximum number of points and weight in % for credits for each subcategory is then determined based on their impact on sustainability and their importance within the category. For example, within the energy efficiency category, the building envelope improvement subcategory has a maximum of 14 points and a weight for credits of 25%, while the energy-efficient HVAC systems subcategory has a maximum of 8 points and a weight of 14%.

Table 3. Projects planned rating categories.

No.	Rating Categories	Planned Points	Planned Weight	Max Points	Max Weight
1	Sustainable site (SS)	40	10%	40	10%
2	Energy efficiency (EE)	52	26.5%	56	28%
3	Water efficiency (WE)	25	12.5%	60	30%
4	Materials and resources (MR)	21	10.5%	24	12%
5	Indoor environmental quality (EQ)	24	12%	24	12%
6	Management protocols (MP)	16	8%	16	8%
7	Innovation and added value (IN)	2	2.5%	10	5%
	Total	180	78.3%	230	105%

Overall, the determination of the maximum number of points and weight in % for credits for the GPRS is based on a comprehensive analysis of the impact and importance of each category and subcategory on sustainability in buildings using the system's indicators through the generic and integrated framework using the available BIM solutions.

5.2. BIM Model Implementation

First, the stakeholders agree on the project goals list and define the BIM uses to perform the corresponding requirements to conduct and simulate various design iterations and ideas. Then, the "Information Delivery Manual" framework and the process maps represent the business needs, data sets, and information exchange requirements. Finally, the proposed framework utilizes several software packages and plug-ins to achieve its sustainability goals. Next, a 3D model of the sustainable office building is designed via Autodesk Revit as the chosen BIM authority tool, due to its popularity among BIM software, using the base case characteristics. The user starts setting up the project by entering the basic project information, as shown in Figure 7. Then, several configurations are implemented, including selecting the study's date, and time range, setting the minimum threshold, plane height, space layouts, building material, thickness, geometry (area and volume), building services, location, and building types. Then, the user sets the project phases and building type from the "Manage" tab, followed by the MEP and building/space-type settings. Finally, the user conducts a primary energy simulation according to zone-based modeling, space-based modeling, and room-based modeling, and the actual energy performance of the building in the operation phase to define data such as the "Heating and Cooling" properties in the dialogue window under the energy analysis section.

The BIM model contains the shared parameters for each GPRS credit and then assigns the sustainable design-related shared parameters to the GPRS template, which could be assessed during the conceptual design stage. Therefore, the framework's primary approach employs the BIM technology potential to comply with the GPRS certification documents in pursuit of the GPRS credits, evaluate the design iterations based on the prioritized performance metrics from the first step, and adjust designs to meet the prioritized metrics. Then, it applies the created GPRS templates with the proposal for conceptual approaches. Finally, the analytical properties interface with Revit data to add environmental properties, as shown in Figure 8. Ideally, the parametric BIM-based framework constitutes different tools and plug-ins using the developed "GPRS BIM_Based Tool" to create an Autodesk Revit API, which incorporates requirements from the GPRS to support the evaluation of the credits to combine and calculate the performance based on the sustainability scores for all categories.

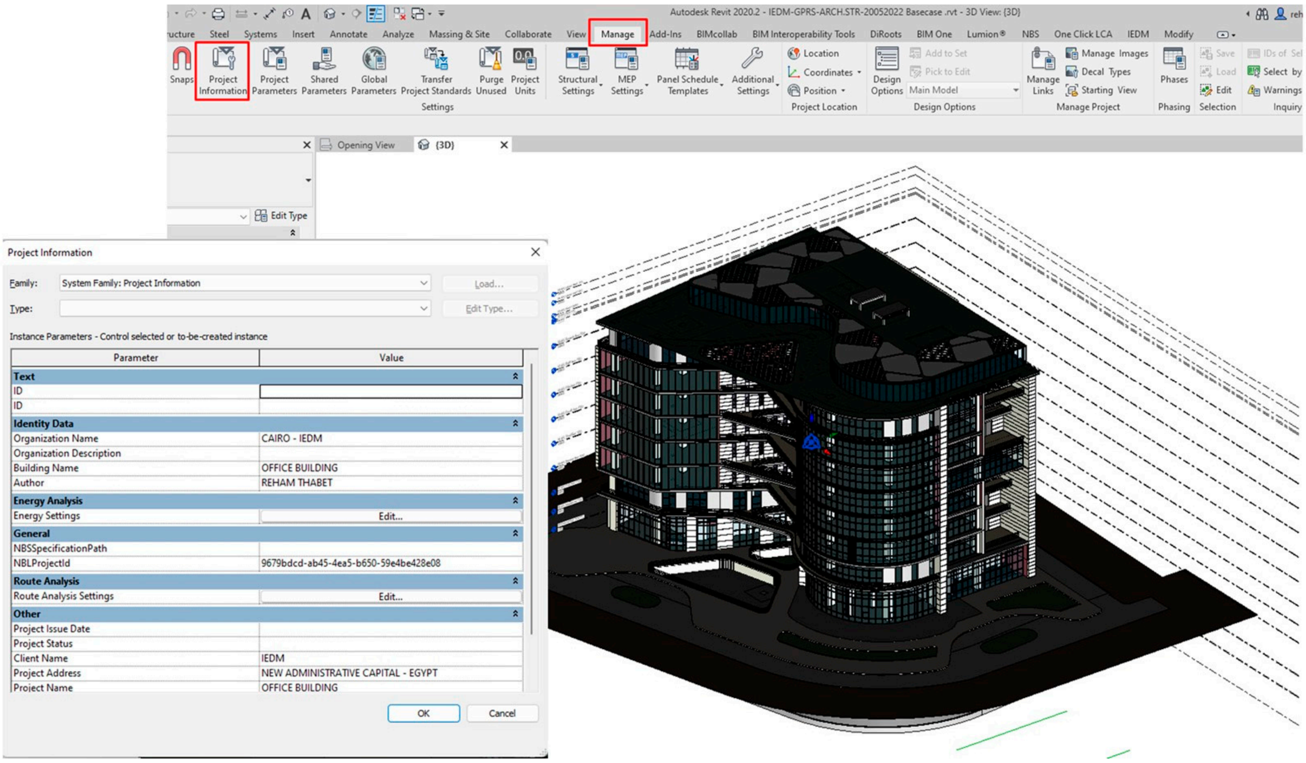

Figure 7. Setting Project Information in Revit.

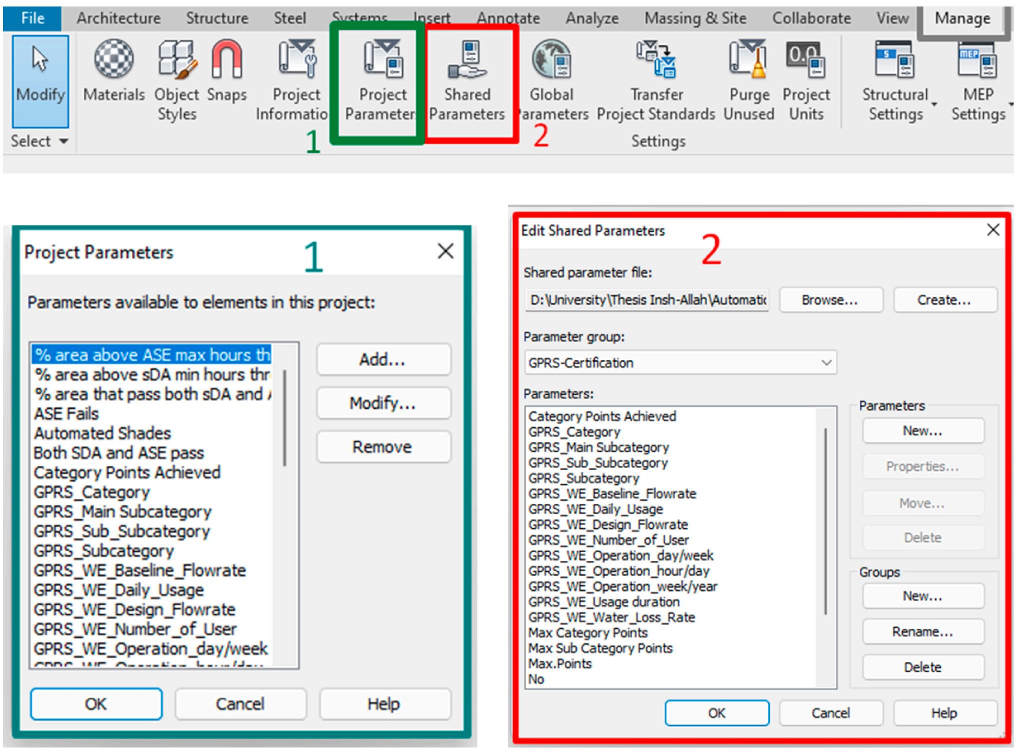

Figure 8. Adding Environmental Parameters.

5.3. Case Analysis

Once the building information model is set up, the user can access the different BIM tools to fit the modularity requirements of the model as a preliminary benchmark for the current BIM solutions and their applicability in the GPRS approach projects. For professional practice, the user customizes a sensitivity analysis phase to conduct several cases and combinations through qualitative and quantitative evaluation for practical implications of the different credits. The analysis is used to generalize the method across different assumptions. As a result, these analyses aim to explore design alternatives before choosing a final design. In addition, these techniques and tools assist the team in exploring new possibilities and experiments with new ways and techniques to reach innovative solutions, reduce the annual operating cost of the building, and discover the critical building elements which affect sustainability.

The case study focuses on developing an integrated methodology for sustainable design decisions using digital tools and stakeholder interactions. The methodology involves complying with various credits and submittals required for GPRS certification, which can be achieved by parameterizing the design and using automated methods for sustainability calculations. Building performance simulation tools, including Google Earth, Design Builder, Insight, and GBS from Autodesk, are used to analyze various aspects of building performance during the early design stages. The modifications in design parameters include orientation, energy consumption, material properties, building envelope design, operating schedule, plug-in efficiency, and HVAC system operation. In addition, the tools provide performance-based analysis reports for several design options, which helps in saving time and communicating the consequences of each design decision to stakeholders.

First, the project achieved 12 points for the sustainable site (SS) category by considering the building orientation, views, heat island effects, surroundings, dedicated bicycle tracks, and parking. Second, Google Earth Maps embedded in ArcGIS were used to define the site location, and different types of maps were defined to compare proposed sites. Third, GPS technologies were used to screen for the "Community services and connectivity" and the "Public transportation access and pedestrian access" credits, gaining 8 points for each credit. The study also developed a set of community service symbols for each function in ArcGIS to calculate the travel distance and evaluate parking potential.

The BIM-based visualization indicates the project's site contextualization of the latest transportation plan for Egypt 2030 and the road map where a new monorail project has a station beside the proposed site. Where the Egypt 2030 Program aims to fulfill the ninth SDG, "Industry, Innovation, and Infrastructure", by increasing the capacity and quality of public transportation means in cities by 50% [32]. Accordingly, developing this assessment method aims to introduce easy-to-use transportation methods for route optimization among multiple locations to decrease car usage and encourage more walkable practices, and allocate bicycle tracks to gain 8 and 4 points, respectively. However, the stakeholders should consider the local demographics, traffic information, and the potential impact of regeneration and introduce new approaches such as green vehicles and carpooling. Ideally, the modeling details at the first stage should provide an outline to include the site location, orientation, layout, solar path, and massing to utilize and define the geographical location of the building. The Cairo city weather file is embedded automatically into the model in Revit, as shown in Figure 9.

Subsequently, a preliminary BIM-based building energy efficiency analysis is conducted using Autodesk Insight through the Revit plug-in to simulate and analyze base case benchmark energy consumption once the model is successfully uploaded to the cloud with default settings. The Autodesk Insight tool uses the EnergyPlus engine to provide quick computations for a solid overview of the construction enhancement possibilities, which assists in optimizing the design solutions against criteria such as solar radiation studies and estimated energy consumption. The significant positive effects of engineering are visible as a graphical demonstration in terms of an output reduction result of approx. 300 kWh/m^2/year, which is achieved in the current case by applying different retrofit design solutions compared with ASHRAE baseline performance values, the Net Zero standard, and the Architecture 2030 Challenge for carbon neutrality.

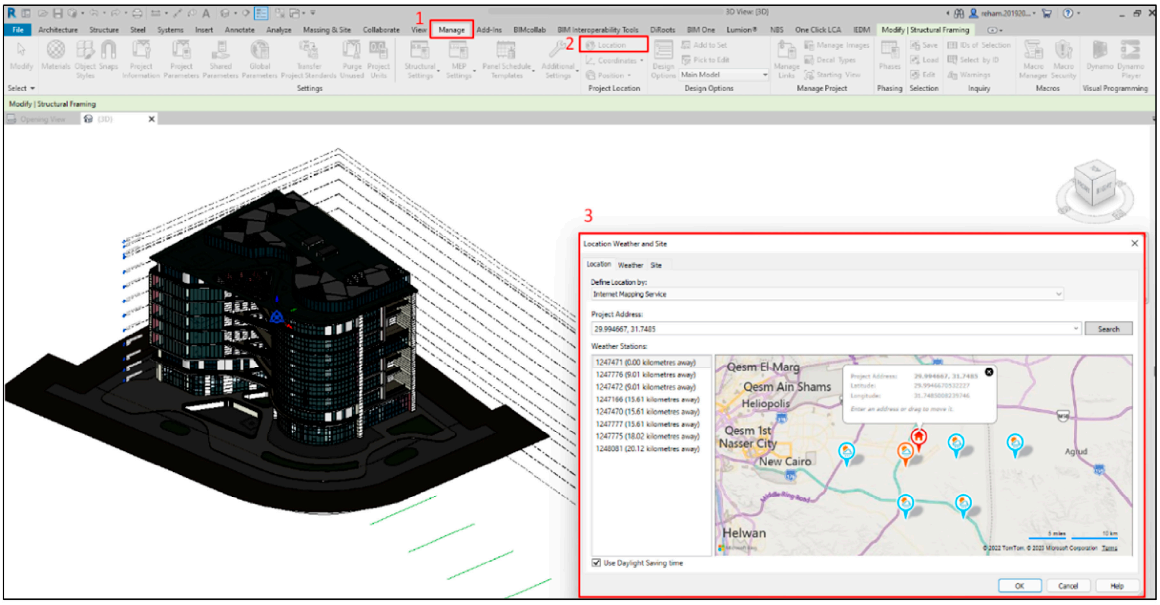

Figure 9. Assigning the building location in Revit.

Autodesk Insight is a powerful tool that allows users to analyze building energy performance and identify opportunities for improvement during the design phase. Its schematic overview input and assigned zone performance provide energy-saving opportunities and aid in designing building management systems. The tool allows users to manipulate and visualize various parameters to assess optimizing building energy performance and identify the best design options for achieving energy savings in the early design stages. It allows comparing different models and standards and evaluates energy consumption using the energy use intensity (EUI) unit. This unit quantitatively measures energy efficiency and analyses building energy performance through various widgets as built-in options for specific energy factors. These factors may include building orientation, WWR for each façade, wall and roof construction, infiltration, lighting efficiency, daylighting, occupancy controls, plug load efficiency, HVAC, and operating schedule. The tool also allows users to evaluate photovoltaic panel payback limits and coverage.

In addition, it uses BIM integration to automatically vary building design input, resulting in immediate performance feedback impact with maximum, minimum, and mean values. Multidisciplinary optimization helps achieve a high-performance level that requires optimal combinations of several strategies instead of applying individual strategies to improve energy efficiency. The tool provides a way for users to analyze and optimize building energy performance, identify opportunities for improvement, and select the solution that gives the best result during the planning and design stages. The modifications proposed by Autodesk Insight should be beneficial in achieving the building energy savings required, demonstrating why different design options have been chosen and quantifying the expected energy savings. The tool allows users to propose energy savings, critical criteria, and methodologies to reach optimum energy savings. Overall, Autodesk Insight is an effective tool for achieving energy efficiency in buildings and improving building sustainability.

Based on the energy auditing and diagnostics shown in Figure 10, the insight result shows the following results and modifications. First, plug load efficiency is considered the highest share of overall building energy use, which accounts for up to 67.41% of total energy consumption for the building. Therefore, the user may use the best practices with key strategies and replace the plug with more energy-efficient equipment. For the efficient artificial lighting systems credit (EE.05), the user determines if the space achieves enough daylight throughout the day for visual comfort. The lighting energy consumption is also very high compared to the heating and cooling consumption. Therefore, the use of automatic daylight controls reduces the level of artificial electric light respective to the use of building windows or skylights, and, in addition, the current lamps are replaced with LED lamps with higher efficiency in a new building, providing a reduction of 76.54 kWh.

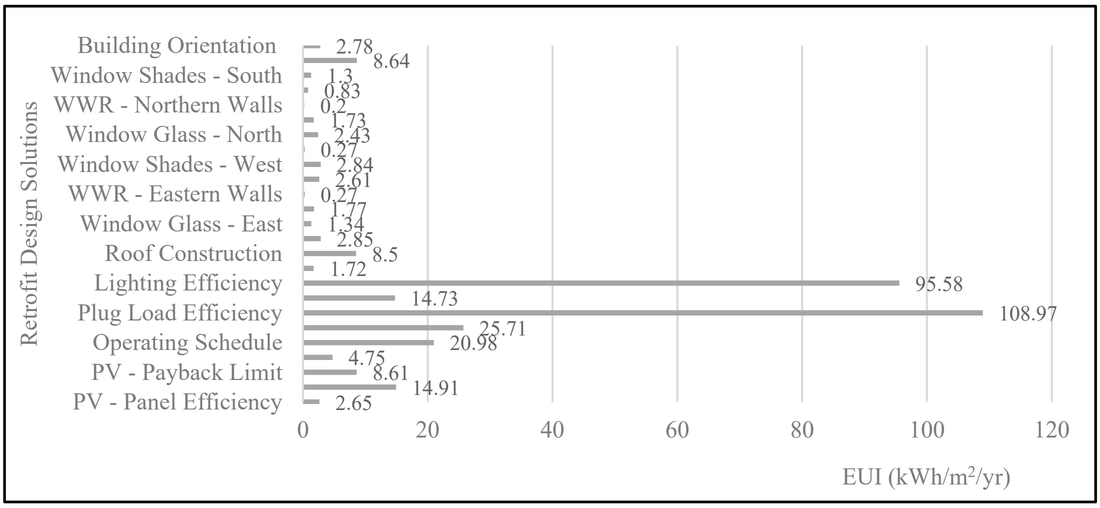

Figure 10. Energy saving due to retrofit design solutions.

The orientation analysis is performed at angles 90, 45, 0, 270, 135, 315, 180, and 225 degrees, to decide the best angle between the building masses. Therefore, the first recommendation is to rotate the building orientation with the longest side in the north direction by 180 degrees, decreasing the energy by 0.66%. In addition, the "Window To Wall Ratio (WWR)" significantly contributes to a building for each façade according to the four orientations, North, South, East, and West, to indicate the energy consumption results. For instance, as the WWR decreased from 95% to 0% in the south façade, energy consumption decreased by almost 13.76%.

The renewable energy sources credit uses the Revit photovoltaic panels to analyze the optimal surface for the placement of the panels, where, in this alternative, the PV-panel efficiency (20.4%) is −33.78 kWh/m^2/yr with a payback limit of thirty years and surface coverage of 90% from Autodesk Revit analysis: PV energy produced: 497,199 kWh/Year. The calculations show the different impacts of using the PV cells on the base case and the modified case, which provides more than 57% of the energy needed for the newly designed building. Undoubtedly, promoting the implementation of passive strategies will save energy and provide additional investments after the payback within a few years [33].

The other analysis is applied to the geometrical configuration, construction materials, U-value, and solar heat gain coefficient (SHCG) value for calculating the primary results. First, the default settings for the base case model calculations are used, which included roofs with a high U-value of 2.0500 W/(m^2·k), uninsulated exterior brick/walls with a 1.4269 W/(m^2·k) U-value, clear glass and skylights with a 1.4269 W/(m^2·k) U-value and 0.86 SHGC, while the shading factor is zero, then press ok and calculate. Revit automatically creates load reports as the calculation output in the project browser. The calculation results for reviewing and documenting load from the schedule view can be exported to an Excel file for further studies. Next, the user modifies the analytical properties and re-runs the calculation by changing materials, the roof terrace system with lower U-values, and using insulation.

Using the exported schedules from the simulation results show that by combining the different characteristics (e.g., roofs, exterior walls, interior walls, ceilings, floors, slabs, windows, and skylights), the cooling and heating consumption measures were reduced by almost 75% for each façade. The saved energy after wall modification concerning the cooling and heating energy is 68.03% and 67.44%, respectively, allowing the building to give twelve more points for the energy efficiency credit. Similarly, an improvement in energy saving compared with the base case by gaining 6 points from the passive heat gain reduction credit with a result of 19.12%, which lies between (19–21%). Besides using energy star and passive equipment, according to the ASHRAE package, the terminal heat pump for HVAC is 7.69%. In addition, two points are added for using motion sensors to slow the HVAC system operation during unoccupied hours and installing a permanent refrigerant leak detection system.

Finally, the report suggests pushing the analysis result to the workflow that connects 2030 Design Data Exchange (DDx) and Insight 360 to optimize energy performance and improve the company's carbon footprint. For example, even though choosing the envelope materials is a key component to achieving energy efficiency, the other materials and resources category uses the renewable materials manufactured and environment materials proofs submittals to gain 4 and 6 points. Correspondingly, the environmental impact data is used for the reliability of particular building products in a specific location to assist and inform building designers of opportunities to mitigate such impacts related to the life cycle of buildings [34].

The project uses the one-click LCA plug-in in Revit to use the cloud-based BIM model properties. The stakeholders agreed to use renewable materials and materials manufactured using renewable energy to gain the 4 points of the (MR.01) credit. Additionally, reducing the overall materials (MR.03) earns 8 points because the building uses more than 20% of materials without finishes. Furthermore, using the standard assembled materials according to the agreed manufacturer specifications, the building can gain 6 points for using environmentally friendly materials. Hence, after validating the choice of wall material for energy efficiency purposes, the one-click LCA simulation allows the comparison of the different options across various impact categories [35]. As a result, the decisions made during the energy analysis regarding several enhancements in the environmental materials affect greenhouse emissions (GWP), the embodied carbon, and the transportation distance of materials and products from the origin to the project site to gain 3 points. The LCA in GPRS is a cradle-to-grave quantification of the environmental impacts of the building considering the entire value chain using data compliant with the ISO14040/44 standard [36]. The embodied carbon benchmark decreases from 3544 kg CO_2e/m^2 to 783 CO_2e/m^2 after modifying the material's life cycle. As a result, the GWP decreased for all of the impact categories using the utilized material solutions to affect the embodied GWP significantly, reducing the selected element's life cycle stages impact from 61.08 t.CO_2e to 19.90 t.CO_2e to gain the 2 points of MP.02.

Similarly, the evaluation module assesses the calculated water-saving ratio/percentages required for estimating the score points. Therefore, BIM can directly assess two credits, achieving 15 points in the design assessment. Water consumption, leak detection, and efficient water equipment are the three main water efficiency aspects for monitoring in the operational stage. First, the green building studio measures the water fixture's efficiency, and the reduced annual potable water consumption is 13.80% greater than 10% to gain the 5 points of the WE.03, assuming the number of people to be 1786. The typical number of people for this building type/size is 368, and the time occupied is 28%. At the same time, the other 10 points for the WE.04 credit are achieved by linking all water sub-meters to the environmental management system (EMS) to facilitate the early detection of water leakage and installing the metering water supply. Further, it accurately tracks the office building's water use and documents their locations and conditions across the site.

5.4. BIM_Based Tool Application

The proposed BIM tool is applied to the case study to simulate the score process determination calculated for each category. As a result, the office building gained a Gold certificate with 4 Green Pyramids, as shown in Figure 11.

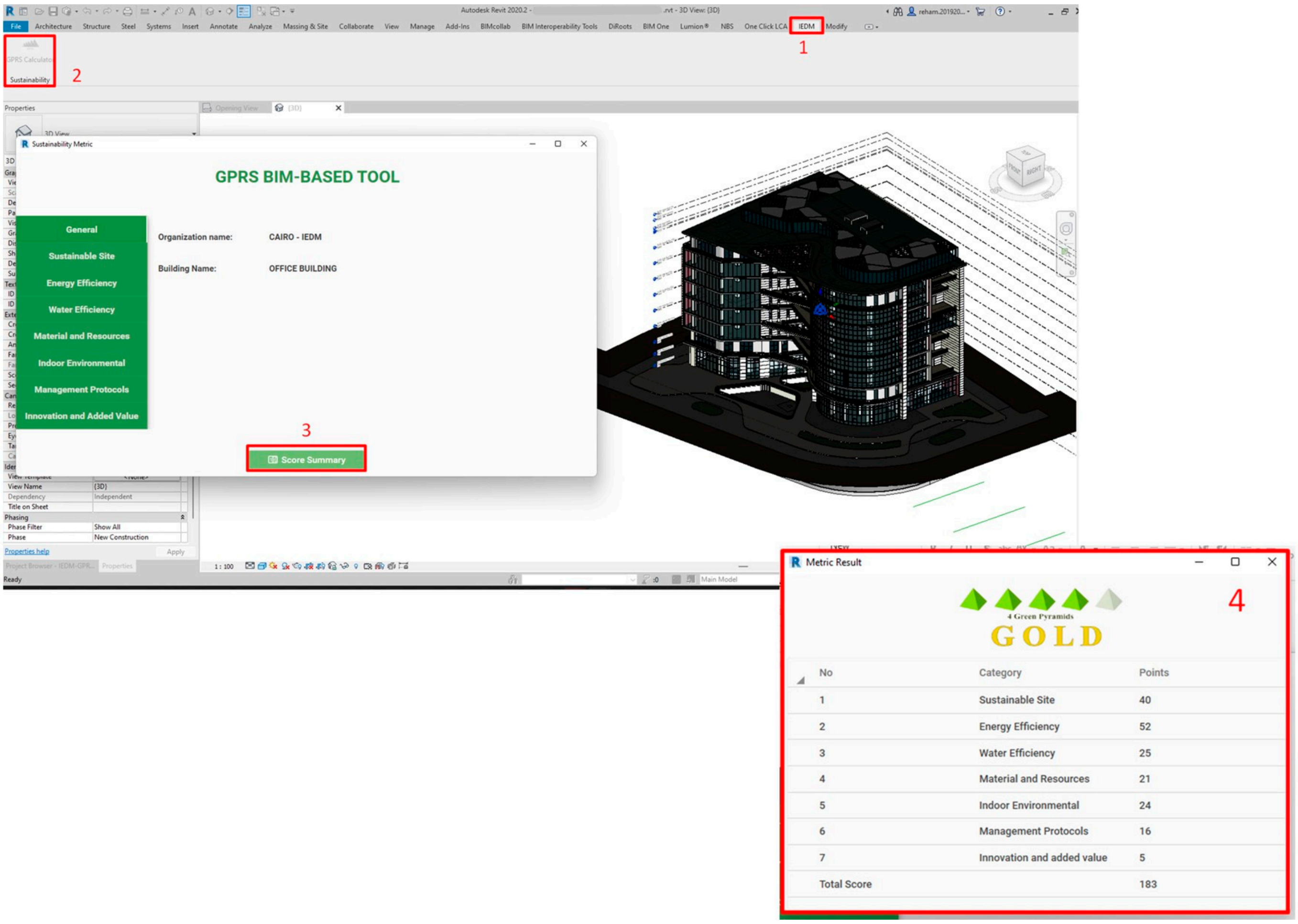

Figure 11. The achieved certification result.

6. Conclusions

The proposed framework incorporates BIM methodology and project management to simplify evaluating the overall GPRS (green pyramid rating system) and documentation processes. The BIM-based tool developed for this framework has successfully verified the optimal design retrofit solutions for the building, resulting in a Gold certification level with a better sustainable design tool through a local office building case study in Egypt. The framework guides the design team in determining the building aspects during the early design stages for various sustainability objectives. It incorporates the BIM methodology and project management to simplify the evaluation of the overall GPRS and documentation processes by preparing the theoretical foundation for sustainability solutions. Further, it integrates the simulation approach using the developed GPRS Revit template with embedded GPRS categories by implementing the technical details using the created shared parameters for assigning the sustainability criteria within the BIM model. This research can be extended in future studies to include updating the created materials database with the necessary local green properties and interfacing it with BIM software to produce a suitable BIM model containing the required green database, considering the economic aspect of both the conventional and circular approaches by adding other decision metrics, such as the cost of operation in addition to achieving more sustainable development goals by considering social aspects. This research can be extended in the future to validate the outputs of the proposed GPRS BIM-based tool against different project types such as residential, commercial, and educational projects. The potential GPRS BIM-based tool users can also subjectively compare the tool and system behaviors, based on their intuition, to decide whether the tool and its results are acceptable and reasonable. They can assess the completeness, depth, practicality, and realism of the proposed tool.

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References

1. de Paula, N.; Jyo, L.K.; Melhado, S.B. Sources of Challenges for Sustainability in the Building Design—The Relationship between Designers and Clients. *Buildings* **2022**, *12*, 1725. [CrossRef]
2. Building Sector Emissions Hit Record High, But Low-Carbon Pandemic Recovery Can Help Transform Sector—UN Report. 2020. Available online: https://www.unep.org/news-and-stories/press-release/building-sector-emissions-hit-record-high-low-carbon-pandemic (accessed on 5 March 2023).
3. Al Horr, Y.; Arif, M.; Katafygiotou, M.; Mazroei, A.; Kaushik, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sustain. Built Environ.* **2016**, *5*, 1–11. [CrossRef]
4. Fauré, E.; Svenfelt, Å.; Finnveden, G.; Hornborg, A. Four Sustainability Goals in a Swedish Low-Growth/Degrowth Context. *Sustainability* **2016**, *8*, 1080. [CrossRef]
5. Bank, L.C.; McCarthy, M.; Thompson, B.P.; Menassa, C.C. Integrating Bim with System Dynamics as a Decision-Making Framework For Sustainable Building Design and Operation. In Proceedings of the First International Conference on Sustainable Urbanization (ICSU 2010), Hong Kong, China, 15–17 December 2010.
6. *ISO 19650*; Organization and Digitization of Information about Buildings and Civil Engineering Works, including Building Information Modelling(BIM)—Information Management Using Building Information Modelling—Part 1: Concepts and Principles. International Organization for Standardization: Geneva, Switzerland, 2018. Available online: https://www.iso.org/obp/ui/#iso:std:iso:19650:-1:ed-1:v1:en (accessed on 10 November 2022).
7. Pikas, E.; Oehmen, J.; Koskela, L.; Thuesen, C. A new framework for construction project definition stage. In Proceedings of the DS 92: Proceedings of the DESIGN 2018 15th International Design Conference, Dubrovnik, Croatia, 21–24 May 2018; pp. 1301–1312. [CrossRef]
8. Mazzoli, C.; Iannantuono, M.; Giannakopoulos, V.; Fotopoulou, A.; Ferrante, A.; Garagnani, S. Building Information Modeling as an Effective Process for the Sustainable Re-Shaping of the Built Environment. *Sustainability* **2021**, *13*, 4658. [CrossRef]
9. Alwan, Z.; Greenwood, D.; Gledson, B. Rapid LEED evaluation performed with BIM based sustainability analysis on a virtual construction project. *Constr. Innov.* **2015**, *15*, 134–150. [CrossRef]
10. Designing Buildings: The Construction Wiki, "Environmental Impact Assessment EIA". 2022. Available online: https://www.designingbuildings.co.uk/wiki/Environmental_impact_assessment_EIA (accessed on 11 April 2023).
11. European Commision, "Nearly Zero-Energy Buildings". 2021. Available online: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en#:~:text= (accessed on 14 April 2023).
12. Solla, M.; Elmesh, A.; Memon, Z.A.; Ismail, L.H.; Al Kazee, M.F.; Latif, Q.B.A.I.; Yusoff, N.I.; Alosta, M.; Milad, A. Analysis of BIM-Based Digitising of Green Building Index (GBI): Assessment Method. *Buildings* **2022**, *12*, 429. [CrossRef]
13. Andújar-Montoya, M.D.; Galiano-Garrigós, A.; Echarri-Iribarren, V.; Rizo-Maestre, C. BIM-LEAN as a Methodology to Save Execution Costs in Building Construction—An Experience under the Spanish Framework. *Appl. Sci.* **2020**, *10*, 1913. [CrossRef]
14. Romano, S.; Riediger, N. BIM as a tool for Green Building Certifications: An evaluation of the energy category of LEED, BREEAM and DGNB. *J. Phys. Conf. Ser.* **2019**, *1425*, 012162. [CrossRef]
15. Shareef, S.L.; Altan, H. Building sustainability rating systems in the Middle East. *Proc. Inst. Civ. Eng.-Eng. Sustain.* **2017**, *170*, 283–293. [CrossRef]
16. United Nations Human Settlements Programme (UNSP). *Building Sustainability Assessment and Benchmarking—An Introduction*; United Nations Human Settlements Programme: Nairobi, Kenya, 2017; ISBN 978-92-1-132728-1.
17. Illankoon, I.C.S.; Tam, V.W.Y.; Le, K.N.; Tran, C.N.N.; Ma, M. Review on green building rating tools worldwide: Recommendations for australia. *J. Civ. Eng. Manag.* **2019**, *25*, 831–847. [CrossRef]
18. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building information modeling for sustainable design and LEED® rating analysis. *Autom. Constr.* **2011**, *20*, 217–224. [CrossRef]
19. Marchi, L.; Antonini, E.; Politi, S. Green Building Rating Systems (GBRSs). *Encyclopedia* **2021**, *1*, 998–1009. [CrossRef]
20. Edeisy, M.; Cecere, C. Energy Efficiency for Egyptian Housing: Code Compliance and Enforcement. *Int. J. Constr. Environ.* **2018**, *9*, 1–15. [CrossRef]

21. Younan, V.A. Developing a Green Building Rating System for Egypt. Master's Thesis, American University in Cairo, New Cairo, Egypt, 2021. Available online: https://fount.aucegypt.edu/cgi/viewcontent.cgi?article=3435&context=retro_etds (accessed on 15 December 2022).
22. Karmany, H.M. Evaluation of Green Building Rating Systems for Egypt. Master's Thesis, American University in Cairo, New Cairo, Egypt, 2016. Available online: https://fount.aucegypt.edu/etds/386/ (accessed on 3 December 2022).
23. Mohamed, A.E. The Implementation of Building Information Modeling (BIM) towards Sustainable Construction Industry in Egypt 'The Pre-Construction Phase'. Master's Thesis, American University in Cairo, New Cairo, Egypt, 2019. Available online: https://fount.aucegypt.edu/etds/508 (accessed on 26 January 2023).
24. Hazem, N.; Abdelraouf, M.; Fahim, I.; El-Omari, S. A Novel Green Rating System for Existing Buildings. *Sustainability* **2020**, *12*, 7143. [CrossRef]
25. Hazem, N.; Fahim, I.S. A step forward enhancing green buildings in developing countries. In Proceedings of the International Structural Engineering and Construction, Cairo, Egypt, 26–31 July 2021; Volume 8. [CrossRef]
26. Attia, S.; Dabaieh, M. The usability of green building rating systems in hot arid climates: A case study in Siwa, Egypt. In Proceedings of the 4th Biennial Subtropical Cities Conference, Fort Lauderdale, FL, USA, 17–19 October 2013.
27. Ammar, M.G. Evaluation of the Green Egyptian Pyramid. *Alex. Eng. J.* **2012**, *51*, 293–304. [CrossRef]
28. Cascone, S. Digital Technologies and Sustainability Assessment: A Critical Review on the Integration Methods between BIM and LEED. *Sustainability* **2023**, *15*, 5548. [CrossRef]
29. BIM Toolkit. Available online: https://www.thenbs.com/knowledge/nbs-bim-toolkit-changes-in-2022 (accessed on 5 May 2023).
30. Olanrewaju, O.; Enegbuma, W.; Donn, M. Systematic Literature Review of Building Information Modelling and Green Building Certification Systems. In Proceedings of the 39th ISARC, Bogotá, Colombia, 12–15 July 2022. [CrossRef]
31. Essawy, A.S.; Mohamed, A.E.; Rana, M.H. Building Information Modeling (BIM) in the Egyptian Construction Industry; Al-Azhar University Civil Engineering Research Magazine (CERM). 2017, Volume 39. Available online: http://www.azharcermjournal.com/CERMF1701/P17-01-02.pdf (accessed on 13 February 2023).
32. UNDP. Terminal Evaluation of UNDP/GEF Project: Sixth Operational Phase of the GEF Small Grants Programme in Egypt; United Nations Development Programme. 2022. Available online: https://erc.undp.org/evaluation/evaluations/detail/14997 (accessed on 7 December 2022).
33. Sorrell, S. Reducing energy demand: A review of issues, challenges and approaches. *Renew. Sustain. Energy Rev.* **2015**, *47*, 74–82. [CrossRef]
34. Onososen, A.; Musonda, I. Barriers to BIM-Based Life Cycle Sustainability Assessment for Buildings: An Interpretive Structural Modelling Approach. *Buildings* **2022**, *12*, 324. [CrossRef]
35. Forth, K.; Braun, A.; Borrmann, A. BIM-integrated LCA—Model analysis and implementation for practice. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *323*, 012100. [CrossRef]
36. *ISO 14040*; Environmental Management—Life Cycle Assessment—Principles and Framework. International Organization for Standardization: Geneva, Switzerland, 2006. Available online: https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en.2006 (accessed on 5 July 2022).