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Article

Accelerating Building Energy Retrofitting with BIM-Enabled BREEAM-NL Assessment

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Abstract: The Paris Agreement requires building retrofitting practices to be more efficient and effective. However, the current practice for building energy retrofitting is lacking behind, and one reason for that is the time-consuming process of energy credit evaluation. Energy performance assessment such as BREEAM-NL in the Netherlands could apply a more automatic approach with the help of building information modelling (BIM) for an efficient building energy retrofitting evaluation process. However, to what extent BIM can help in accelerating energy performance evaluation in the BREEAM-NL certification process is under-examined. This paper first combines literature findings with practical interviews from a case study organization to present a holistic overview of the potential for automating energy-related credits evaluation in BREEAM-NL using BIM. To understand the possible impacts of such transition, a responsible, accountable, consulted, and informed (RACI) matrix is developed to map the impacts on different actors involved. Furthermore, to help practitioners in an organizational context to adopt a BIM-enabled energy credits assessment workflow, the case study organization is studied to (1) understand their current BIM use status; (2) propose a suitable starting point to take toward a BIM-enabled energy performance assessment for building energy retrofitting. Finally, the proposed starting point is demonstrated using a customized application, and the project team's feedback is used to verify its efficiency and future directions are identified.

Keywords: building energy retrofitting; building information modelling (BIM); energy performance evaluation; BREEAM-NL; energy transition; RACI matrix

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1. Introduction

In 2015, 196 different countries signed the Paris agreement to tackle the climate challenges by reducing carbon emissions. In total, the involved countries are responsible for 96.5% of the total emission. This agreement obliges countries to transform their activities on different levels and to be environmentally, socially, and economically ready for the future [1]. The Netherlands signed the Paris Agreement as well, and the conditions stated in the agreement are translated by the Dutch government to a National Climate Agreement (NCA). The central goal of the NCA is to reduce the Netherlands' greenhouse gas emissions by 49% by 2030, compared with 1990 levels, and a 95% reduction by 2050 [2]. The green revolution has urged the architecture, engineering, and construction (AEC) sector's transition, as approximately 35% of the total energy consumption in the Netherlands is accounted for by the building industry [3]. As a result, the Netherlands is on the cusp of a sustainable energy transition of the built environment and the adaptation of the seven million homes and one million buildings [4].

One of the major challenges to achieving sustainable energy transition of the built environment is the state of the existing building stock. Evaluating and optimizing the energy performance of the building is an important part of sustainable building retrofits. However, not knowing the current status and the potential energy benefits in time hinders the implementation of building energy retrofitting. Green building certifications can serve as useful instruments of guidance in this process. Through in-depth evaluation metrics and a decision support framework, green building rating systems can help designers in improving the sustainability of buildings [5].

There are several different environmental certification methods prevalent in the Netherlands such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Enegielabel, GPR Gebouw, etc. Amongst these, BREEAM is one of the most widely accepted choices of environmental assessments [6]. The Dutch Green Building Council (DGBC) has developed a national adaptation of the guideline named BREEAM-NL in 2009. The requirements of the certification system were tailored to align with the national standards and legislation. Ever since, its popularity and the total BREEAM-NL certified area has been increasing steadily. Due to a lack of data, especially for the existing building stock's renovation projects, the sustainability assessments in practice are often conducted at the end of design stages with time-consuming manual data gathering processes, when the scope for changes or corrections is too little [7–10].

The development of building information modelling (BIM) brings the potential to improve this green building evaluation process and accelerate the building energy retrofitting practice. The need for data-driven design has been boosting the application of BIM in the AEC industry. Lately, the use of BIM for the creation of sustainable assets has been gaining momentum. This convergence of BIM and green buildings is often referred to as Green BIM. Krygiel et al. [11] were one of the early works that discussed the potential of BIM for sustainable project delivery. Integration of multidisciplinary information and facilitation of performance analyses with regards to energy, thermal comfort, daylighting, etc., are some of the commonly known advantages BIM can offer for green building projects. Lu et al. [12] identified that BIM-supported lifecycle functions, environmental analyses, and green building assessments are the three primary facets of integrating BIM with green buildings.

Despite the increasing number of studies providing evidence to support these claims, BIM is not being actively used for sustainability assessments or green certifications [13,14]. Furthermore, Ayman et al. [15] concluded that further work must focus on real-life problems identified from the industry and propose solutions in response to that.

The main question that will be answered in this research is, therefore:

> *To what extent and how can BIM help in accelerating building energy retrofitting implementation in the energy performance evaluation process of BREEAM-NL certification practice?*

The research has three main aims:

AIM 1: To investigate in industrial practice, supported by literature, the possibilities of BIM application in building energy retrofit assessments for BREEAM-NL certification;
AIM 2: To understand the impacts on actors involved in the transition to an automated BIM-enabled approach;
AIM 3: To propose context-specific starting points in response so that the building energy performance evaluation can be automated, and the building energy retrofitting process can be accelerated.

The rest of the paper is structured as follows:

Section 2 presents the context of the research, including both literature findings and an introduction to the case study organization;
Section 3 explains the methodology followed in this research;

Section 4 presents the possibilities for BIM to enable automatic energy-related credits evaluation in BREEAM-NL assessment;
Section 5 presents the possible impacts for different actors involved based on a responsibility, accountable, consulted, and informed (RACI) matrix;
Section 6 makes a customized recommendation starting point for this case study organization based on their BIM maturity and workflow and the recommendation is demonstrated using a custom application for one selected credit. The impacts are validated by experts;
Section 7 concludes the findings and discusses the limitations and future directions.

2. Context of The Research

2.1. BREEAM-NL for Building Energy Retrofits

The world is witnessing a paradigm shift leading to the evolution of building codes and guidelines to enable and evaluate sustainable developments, such as the development of green building councils [16], which promote green building assessments (GBA). The Building Research Establishment's Environmental Assessment Method (BREEAM) has become more popular in European countries [17] due to its flexibility for adaptation by the local regulations. BREEAM-NL is the national adaptation of this international scheme tailored to the regional context of the Netherlands. An important distinction has been made in the roles involved in the accreditation process. BREEAM international only has a licensed assessor that is responsible for assessing the documentation submitted by the design team, while BREEAM-NL has two functional roles: BREEAM-NL expert and BREEAM-NL assessor. A BREEAM-NL expert is a trained content and process manager that can support the developer/ the client in the design and construction phases to meet the BREEAM-NL requirements. A BREEAM-NL assessor is an independent professional working for a licensed organization. The assessor is responsible for examining the evidence submitted by the expert and preparing an assessment report based on which DGBC issues the final certification decision.

The BREEAM-NL assessment starts with the client's ambition, expressed as a program of requirements, which guides the design process for architects and mechanical, electrical, and plumbing (MEP) designers. The design teams provide information to the BREEAM-NL team that will be used to verify the compliance of the design with the certification requirements. The interaction and feedback will be used to optimize the design. The BREEAM-NL team submits the documentation to an assessor. The chaotic distribution of information is one of the biggest challenges of green building assessments (GBA) [18]. This manual way of green building assessments is not only time consuming but also error prone [19]. A more efficient and intelligent way of data acquisition and assessment system can greatly benefit project teams in achieving green certifications.

BREEAM-NL rating system has three hallmarks depending on the type of the project: new construction and renovation, in use, area development and re-development. Large-scale renovations or deep energy retrofits that involve changes to the building envelope, installations, or the building function fall under the first hallmark: new construction and renovation. Energy is one of the ten sustainability topics covered in the BREEAM-NL guideline. The requirements related to this category weigh the highest, amounting to 19% of the total available points [20].

To obtain a BREEAM-NL certificate for a renovation project, the project teams must demonstrate compliance with numerous requirements laid out in the assessment guideline. These requirements concern improvement in the performance of the asset as compared with the existing baseline situation. Additionally, based on the total number of points obtained, the certification decision is made. This entire process is time consuming and laborious, because it requires large amounts of interdisciplinary information distributed between several different stakeholders. Moreover, the availability of accurate information about the existing building condition and its performance during the design phase is crucial for a successful renovation project.

In the Netherlands, approximately half of the housing stock was built before 1975, and nearly 40% of the usable surface area in non-residential building stock was built after 1994 [21]. Therefore, most of these assets, especially in the non-residential sector, are not energy efficient and do not yet have a registered energy label. Energy renovation of existing buildings is instrumental to meeting future sustainable requirements [22]. As mentioned, BREEAM-NL assessment can help make optimal designs through energy performance metrics, and automating this evaluation process can improve the building energy retrofitting practice.

2.2. BIM-Enabled Energy Performance Assessments

BIM refers to the ICT technologies, working processes, and policy guidelines that together enable the creation and management of information related to a building throughout its lifecycle [23]. By integrating the different data sources in a single information model, BIM not only facilitates n-dimensional analysis but also allows for smoother, real-time collaboration between project stakeholders. In light of these advantages, the majority of the AEC organizations started to move away from two-dimensional CAD workflows toward a data-oriented, BIM approach in the past two decades. This transition occurs in incremental maturity stages starting from object-based 3D modelling to network-based integration of all disciplines [24].

Energy performance assessment and compliance verification is one of the many opportunities created by the introduction of BIM. For example, through building energy models (BEM), BIM can enable the assessment of the performance of an asset against energy efficiency standards. It can also help identify the best renovation and retrofitting solutions by allowing for a comparison between existing building performance and the expected performance after selected changes [25]. By enabling performance evaluation in concurrence with the design process, it empowers design teams to make sustainable choices in the early design phases of a project when the flexibility for changes and corrections is the highest. The use of BIM also offers the possibility of automating the compliance verification process for green certifications, which greatly reduces the time and errors associated with traditional methods of sustainability assessments. Storing information related to green certification requirements in the BIM model could also fasten the process of producing necessary documentation. The use of BIM can, therefore, benefit the energy assessment process in three ways:

- By enabling performance evaluation in concurrence with the design process, it empowers design teams to make sustainable choices in the early stages of the project;
- By replacing the traditional, manual methods of evaluation with an automated approach, it makes the process of verifying compliance with regulations or green certification requirements more efficiently;
- By proper data management and linking information sources, it facilitates and streamlines the massive document management required for achieving these certifications [12,26,27].

Despite the increasing number of studies providing evidence to support this claim, the industry is struggling to capitalize on the benefits of green BIM. As of now, Lu et al. [12] identified several challenges facing the implementation of BIM-based energy and sustainability assessments such as a lack of appropriate technology, interoperability between BIM and BEM tools, and the integrity of BIM models. Furthermore, most of the studies (more than 70%) on the integration of BIM and sustainability assessments focused on LEED certification, while knowledge regarding BIM applicability for other certifications is insufficient [28]. Based on the existing literature, it is estimated that about 67% of LEED credits can be linked to BIM, whereas merely 24% of BREEAM credits have been linked to BIM [5]. Furthermore, the requirements in BREEAM-NL are aligned with the Dutch legislation, and these are not yet embedded into the commonly used software programs. Therefore, until the release of a relevant commercial software, in order to automate assessments, technical infrastructure has to be developed by the project teams themselves. Table 1 provides an overview of the software tools used for automated assessments of various sustainability rating systems. It can be seen that BREEAM-NL was not discussed before.

Table 1. Common software tools used for sustainability evaluations (derived from Carvalho et al. [5]).

Software	Applied Certifications [1]
Autodesk REVIT (in combination with API/ Dynamo)	BREEAM International 2013, BREEAM Offices 2008, LEED NC
IES-VE	BREEAM UK 2011, BREEAM UK Refurbishment and Fit-out 2014, LEED NC
TAS	BREEAM UK 2011, LEED NC
Energy Plus	BREEAM UK 2011, LEED NC
Green Building Studio	LEED, BREEAM UK Refurbishment and Fit-out 2014
Visual Studio	BREEAM Europe Commercial 2009
Excel	BREEAM International 2013, LEED NC

[1] Software tools used in previous academic works for the listed rating systems.

2.3. Energy-Related Credits in BREEAM-NL

The BREEAM-NL assessment guideline is divided into nine "categories" based on the topic they deal with. Figure 1 shows the different categories and their weightage in the new construction and renovation hallmark of BREEAM-NL. Energy category has the highest weightage at 19% followed by health and comfort at 15% and materials at 12%.

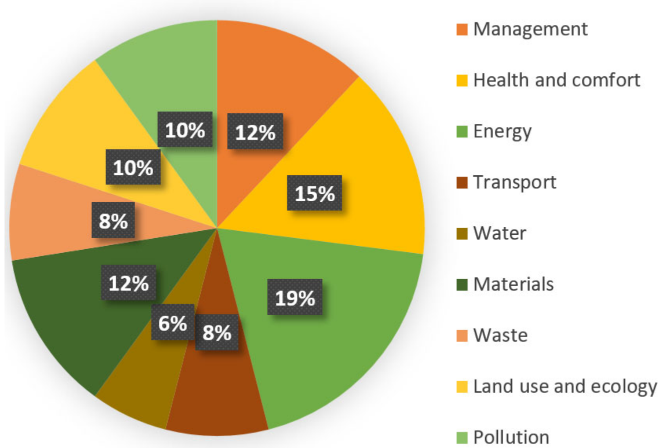

Figure 1. BREEAM-NL new construction and renovation—composition.

The energy category of BREEAM-NL is divided into credits aiming at measures to improve the energy performance of the building through design features and efficient installations. These credits are worth a maximum of 29 points, plus an additional 2 points available for exemplary performance. The description of the credit requirements and associated points are provided in Table 2. This table serves as the input for the semi-structured interviews conducted to investigate the potential of using BIM for automated assessments in Section 4, the associated impacts of BIM use on different actors in Section 5, and recommended digitalization starting points in Section 6.

Table 2. Overview of the credits in the energy category, BREEAM-NL 2014 v2 (derived from the BREEAM-NL guideline).

Credit Description	Max Score	Sustainability Objective	Assessment Method
ENE 01: Energy efficiency	15	To encourage design optimization that will result in the lowest possible CO_2 emissions due to building-related energy consumption	Percentage improvement in energy performance coefficient (EPC) as compared with the energy performance standard (EPN) has to be calculated
Exemplary performance	2	To promote exemplary performance through CO_2 neutral building (parts) and dynamic energy modelling	Calculation of energy generation and demands of the building through dynamic modelling tools
ENE 02: Sub-metering of energy consumption	2	To ensure that the significant energy consumption zones within a building are metered and monitored separately	Design verification to ensure that energy sub-meters are placed in the significant consumption groups
ENE 04: Energy-efficient outdoor lighting	1	To promote the usage of energy-efficient lighting fixtures and reduce outdoor lighting related CO_2 emissions	Specific lighting power per lux calculation and verifying if it is under 0.1 W-Lux/ m^2.
ENE 05: Application of renewable energy	3	To encourage the use of renewable energy sources	Feasibility study for the application of renewable energy sources and the resulting percentage reduction in carbon emissions
ENE 06: Minimizing air filtration	1	To promote CO_2 reduction through efficient design that minimizes heat and cold losses	Qualitative design verification to ensure the application of appropriate interventions for minimal loss of heat and cold
ENE 07: Energy-efficient refrigeration and cold storage	1	To promote energy savings and CO_2 reduction through the use of efficient cold storage equipment	Verifying that the specifications of the refrigeration equipment meet the requirements
ENE 08: Energy-efficient elevators	2	To promote energy savings and CO_2 reduction through efficient elevators	Verifying that the specifications of the elevators meet the requirements
ENE 09: Energy-efficient escalators	2	To promote energy savings and CO_2 reduction through efficient escalators	Verifying that the specifications of the escalators meet the requirements
ENE 26: Assurance of thermal quality of the building	2	To guarantee the thermal quality of the building envelope	Thermographic survey on-site to check for thermal irregularities and quality of insulation
Total max. points	31		

3. Research Methodology

A mix of methods have been applied (shown in Figure 2) in this research, namely desk study, semi-structured interviews, RACI matrix actor mapping, and the development of a custom application to demonstrate the recommendations and validation of these recommendations through semi-structured interviews.

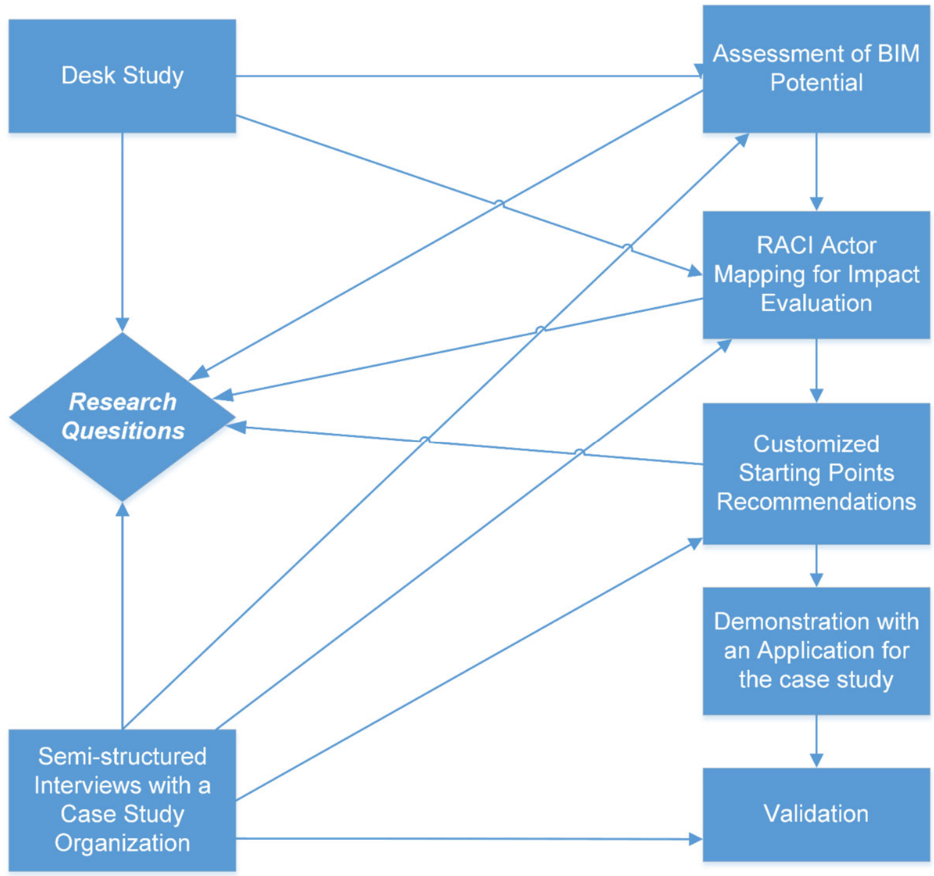

Figure 2. Methodology framework.

This study starts with a desk study on BIM-based energy performance and green building assessments. A comprehensive qualitative analysis of the requirements of the energy credits stated in the BREEAM-NL new construction and renovation 2014 v2 guideline [29] for building energy retrofits has been performed. These requirements are then mapped to relevant stakeholders, BIM uses, and automation possibilities for each credit. This serves as a starting point for mapping the possibilities of using BIM for automation and also as an input for semi-structured interviews.

This research is practice-oriented, with a focus on the multidisciplinary nature of BREEAM-NL energy evaluations and problems experienced by industry professionals. Therefore, we have embedded this research in a case study organization, and expert interviews have been conducted throughout the process, starting from problem statement initiation, process and actor mapping, and recommendations for energy assessment implementation strategies based on the BIM maturity, toward validation of the proposed strategies in the end. A total of ten semi-structured interviews have been conducted and the duration of each interview ranged from 60 to 75 min to discuss topics listed in Table 3. The interviews have been performed with interviewees' consent and the results have been anonymized.

Table 3. List of interviewees and topics discussed.

Actor Code	Role	Experience	Interview Topics
A1	BREEAM expert and sustainability consultant	3+ years' experience in BREEAM projects	(1) Workflow and methodology of energy assessments in BREEAM-NL (2) Means of information exchange and collaboration with other stakeholders (3) Awareness and use of BIM for energy assessments (4) Foreseeable challenges for BIM integration (5) Time taken for energy assessments (6) Most critical/time-consuming steps in the process
A2	BREEAM expert and sustainability consultant	5 years' experience in BREEAM projects	
A3	BREEAM expert and sustainability consultant	13 years' experience in BREEAM projects	
A4	Energy specialist	5 years' experience as Energy consultant	
A5	Energy specialist	5 years' experience as Energy consultant	
A6	Architect (external actor with a collaboration history with the case study organization)	20 years' experience in architectural design	(1) Role and level of involvement in the BREEAM-NL assessment process (2) Awareness of the BREEAM-NL requirements (3) Awareness and use of BIM for energy assessments (4) Foreseeable challenges for BIM integration (5) Time spent on BREEAM-NL energy assessments (6) Most critical/ time-consuming steps in the process
A7	MEP designer	30 years' experience in MEP design	
A8	MEP designer	12 years' experience in MEP design	
A9	BIM manager	9 years' experience with BIM	(1) Position of the BIM department in the organizational structure (2) Organizational culture, drivers, and challenges of BIM (3) Level of involvement in BREEAM-NL projects (4) BIM maturity level of the organization (5) BIM tools and processed adopted
A10	BIM and digitalization lead	15 years' experience in product development and digitalization	

The semi-structured interviews of actors involved in energy assessments of BREEAM-NL help in four aspects:

- Supplementing and validating the possibilities of using BIM for BREEAM-NL energy credits in building energy retrofits, identified from desk study;
- Understanding the responsible, accountable, consulted, and informed actors in the process and the current implementation status of BIM in BREEAM-NL assessment;
- Proposing customized starting points in response to the current BIM use status for BIM-enabled energy performance evaluation;
- Validating the proposed starting points and the associated applications.

A responsible, accountable, consulted, and informed (RACI) matrix [30,31] has been made to understand the actors involved and their roles. This serves as the basis for examining the impacts and potential barriers of BIM-enabled workflow on various actors in this process.

To enable the validation of the proposed steps, an application for one example energy credit using REVIT API 2021 has been developed to implement the recommendations. Using the data from the desk study and practical interviews, a custom tool has been developed in C# that can automate the assessment process of the identified example credit.

4. Integration with BIM: Possibilities

After the analysis of the requirements stated in the guideline and interviewing experts, it has been identified that there are two types of data requirements for energy assessments:

- Data about building geometry, characteristics, and specifications of the components used in the building, which can be obtained from BIM models;
- Performance-related data can either be obtained from dynamic BEM models or static calculation methods using the information from BIM models.

For the first category, BIM can be used for intelligent data acquisition and rule checking. Therefore, for the evaluation metrics that concern only this type of information, the assessment can be fully automated if the required information is stored in the BIM models. However, in the case of evaluation metrics that require both building geometry and performance-related data, the integration of BIM data with performance data obtained from software tools approved by the DGBC is required to make energy assessments for BREEAM-NL. Therefore, apart from the availability of data, the interoperability between BIM and BEM tools is detrimental for automation.

For performance-related criteria, two kinds of assessments are possible: dynamic simulations and static calculations. Static methods of calculation make use of pre-defined factors and several assumptions for the assessment of building performance. Building related information for these assessments can be fully extracted from BIM models given an appropriate level of detail (LOD) [32] in the models. These methods are less complex, but fail to capture the impact of environmental and operational dynamics on building performance [33]. Dynamic calculation methods make estimates on building performance considering the dynamic weather conditions, occupant usage, and varying energy demands and, therefore, yield more accurate results. These assessments are carried out in an external energy analysis tool such as Integrated Environmental Solutions Virtual Environment (IESVE) or Green Building Studio (GBS). Table 4 provides an overview of the potential BIM use for automation for the energy credits evaluation.

Table 4. BREEAM-NL energy credits vs. BIM uses.

Credit	BIM Uses	Input Data Source	Automation Possibility
ENE1	Data extraction Performance analysis and prediction Compliance validation	BIM + BEM	Partial
ENE2	Data extraction Documentation Compliance validation	BIM	Full
ENE4	Data extraction Documentation Compliance validation	BIM	Full
ENE5	Data extraction Performance analysis and prediction Compliance validation	BIM + BEM	Partial
ENE6	Documentation Design reviews	BIM	None

ENE7	Data extraction Documentation Compliance validation	BIM	Full
ENE8	Data extraction Documentation Compliance validation	BIM	Full
ENE9	Data extraction Documentation Compliance validation	BIM	Full

5. Integration with BIM: Impacts on Actors

This section starts with a responsible, accountable, consulted, and informed (RACI) matrix developed based on the results from the desk study and the semi-structured interviews from the case study organization (Section 5.1). The RACI matrix is then used to evaluate the potential impacts on actors and implementation in the case study organization (Section 5.2).

5.1. The RACI Matrix for BREEAM-NL Assessment

Table 5 presents the developed RACI matrix for BREEAM-NL assessment in the case study organization, and the BREEAM-NL expert is a special role in this process as described in Section 2.1. It must be noted that these responsibilities relate to design-phase assessment only. The post-construction review is based on as-built information, in which case, BIM can be used to produce documentation.

Table 5. BREEAM-NL energy credits vs. stakeholder responsibilities.

Credit	Input Data for Assessment	Stakeholder				
		BREEAM-NL Expert	Architect	MEP Designer	Sustainability Engineer	Contractor
ENE1	EPC Calculation	R				
	Inputs: (a) Geometry and building envelope related information		A	I	C	I
	(b) HVAC system details		I	A	C	I
	(c) Renewable energy system details		I	A	C	I
	Use of certified calculation software	R				
ENE2	Significant energy consumption zones and	R	I	A	I	I

	placement of energy sub-meters					
	Information on if sub-meters are connected to a building management system	R	I	A	I	I
ENE4	Luminous flux, power, and target illuminance area of lighting fixtures	R	I	A	I	I
	Purpose of lighting fixtures: utility/ decorative	R	C	A	I	I
	Presence of automatic dimming or switching options	R	I	A	I	I
ENE5	Feasibility study and carbon emission calculations	R	I	I	A	I
ENE6	Qualitative assessment of design features	R	A	I	I	I
ENE7	Specification of cold storage equipment	R	I	A	I	I
ENE8	Specifications of elevators	R	I	A	I	I
ENE9	Specifications of escalators and moving walks	R	I	A	I	I
ENE26	On-site thermographic survey and air permeability measurement	R	I	I	I	I

R = responsible for the assessment activity; A = accountable for input information; C = consulted for design optimization; I = informed about design and changes.

In general, the actors marked responsible lead the task of the credit assessment and compliance verification. This is usually the BREEAM-NL expert appointed by the client. They are responsible for the collection of the design data, evaluating the status of compliance in accordance with the BREEAM-NL requirements and creating suitable documentation to do the same. The expert (s) takes the lead role in the assessment process. Starting from performing a quick scan to identify the target BREEAM-NL credits for a project, the expert provides guidance and support throughout the design and construction phases. The responsibility of verifying the compliance with BREEAM-NL requirements and compiling the evidence report to support the same also lies with the expert. In general, the information sources and the assessment tasks for each credit lie with different stakeholders involved in a project.

The actors marked accountable are the authors of the design information such as the mechanical, electrical, and plumbing (MEP) design details used for the EPC calculation in ENE1 or information regarding the energy concept used for the assessment of the credit ENE5. Therefore, the responsibility of providing accurate input parameters for the assessments lies with them. As seen in the brief overview of input information for each credit and the stakeholders responsible for it in Table 5, the primarily accountable stakeholder for most of the energy assessments is the MEP design team. This is because the credit requirements relate mainly to installations or light fixtures, and this information can be found in MEP models or drawings. Whereas, the responsible party for the assessments is the BREEAM-NL expert in all cases. Few criteria in ENE1 and ENE6 relate to geometric information, for which the architect will be accountable.

The actors marked consulted are not primarily involved in the assessment process but rather provide inputs for design optimization in case of non-compliance. For example, to gain a point for ENE 4, all outdoor lighting must be non-decorative. While the lighting design is done by the MEP team, the architect is consulted in the process to ensure that the lighting requirements aligns with the architectural design idea. Sustainability engineers, if appointed for the project, are mainly consulted for credits dealing with energy consumption or carbon reduction.

Additionally, the actors marked informed are not concerned with the design stage assessment itself but the outcome of the assessment influences their scope of work. Such as, the contractor is not a part of the design certification, but all the starting points used for the assessments will be translated into a technical program of requirements for the construction phase. Therefore, they are kept informed of the target credits, status of compliance, and input parameters that cannot be changed during construction.

5.2. RACI-Based BIM Integration Impacts

Based on the RACI model presented in Table 5, besides the expert in the evaluation process, architects and MEP designers are very important, as they are accountable for the inputs used in the energy performance evaluation process for almost all the credits. These are also the actors responsible for the creation of the BIM models and, therefore, have a key role in a BIM-based evaluation process.

However, at this moment, the interview results have indicated that BIM is not being actively used for BREEAM-NL energy assessments in the case study organization (A1–A3). The interviewees expressed that the link between BIM and energy assessments for BREEAM-NL, in particular, is not known to the practitioners in the case study organization (A4). While the other departments of the organizations are making significant progress in BIM adoption, this subject is not considered relevant to the energy team (A2, A9). Knowledge about how many of the credit assessments can be automated and what information must be requested from each stakeholder is not known (A1–A5).

Interestingly, in this case study organization, the players from the BREEAM-NL expert team are not only open but rather enthusiastic about moving to a BIM-enabled partial automatic workflow. They described their current scope of work as being dominated by “administrative tasks” of gathering information from multiple stakeholders, whereas they would rather spend that time on consultancy and advising the clients on how to make their assets more energy efficient (A2, A3).

However, as seen in the RACI matrix, some resistance has also been observed and is also logical from the design team members interviewed, as they will need more time in preparing such information. They have expressed concerns over the increase in modelling time to deliver BIM models that are suitable for automated assessments (A6, A7). Time and budget constraints have been also pointed out as barriers that may prevent its implementation in practice (A2).

Furthermore, it has also been observed from the documentation of BREEAM-NL projects that while most of the projects handled by the BREEAM-NL team do have a BIM execution plan (BEP), this document has not yet included the BREEAM-NL team as a relevant stakeholder, nor has it described their requirements, deliverables, and responsibilities. This is because BIM for sustainability assessments is not yet a commonly adopted strategy in practice, and therefore, there is not sufficient guidance available to help execute the same. The interviews have also revealed that the BIM models handed over by the design teams are often not suitable for energy analysis. Due to poor interoperability between BIM and BEM tools, the model has to be either cleaned or re-modelled before running an energy simulation (A2, A5). This process is highly time consuming. Since dynamic simulations are not mandatory, static methods are often used. However, even in this case, all the information required for assessments is not present in the BIM models and is often requested through email or other digital communication platforms (A4).

Therefore, to implement a BIM-enabled workflow for energy performance evaluation, it is crucial to obtain these actors' support and link the assessment team with them at the beginning of the process with established guidelines on how to work together. These findings also show that support from the client, contractual changes, and comprehensive policy documents guiding the integration of BIM and sustainability assessments will be needed for a successful implementation.

There has been also the question of to what extent the switch to a fully BIM-based workflow is justified. Interviewees have pointed out that for critical or time-consuming credits, the use of BIM has obvious advantages such as significant improvements in building performance and efficiency of the design process, which would be welcomed by all the project stakeholders. However, some interviewees have held the opinion that not all the credits that can be automated using BIM ***need*** to be automated (A3, A7, A8). Credits such as ENE8 or ENE9 relate to the use of energy-efficient transport equipment. It is theoretically possible to include this information within BIM models and create rules that can verify the compliance of a given model against them. However, the specific requirements stated in the assessment guideline are numerous. The amount of effort that goes into the creation of the automation infrastructure and information-rich models does not outweigh the benefits in this case. It is also important to consider the current level of BIM adoption in a team before proposing strategies for digitalization and automation of assessments. Progress to higher BIM maturity can be met with resistance if it is not approached in small incremental steps (A9, A10). Therefore, from a practical perspective, it is lucrative to identify the most critical topics of energy evaluations for the switch to a BIM-based approach. As a result, customized recommendations are given to the case study organization based on their current practice status of BIM and BREEAM-NL assessment for energy performance assessment.

6. Customized Recommendations

6.1. Energy Performance Evaluation with BIM—Starting Points

The extent to which BIM-based energy assessments are possible greatly depends upon the BIM maturity stage [23,34] the project team operates at. The benefits offered by BIM and integration with sustainability assessments increase with each stage [5,26]. As can be seen from Table 5, most of the energy credits involve multiple stakeholders, and therefore, real-time information exchange between these disciplinary models is required for the automation of assessments for these credits. This is only possible at a higher BIM stage. Whereas, for credits that have a single information source, it is possible to automate the assessments at lower BIM stages provided that the disciplinary models are information rich. Therefore, when approaching the automation of performance assessments for energy efficiency and green certifications, it is important to consider the stakeholder in question as well as the BIM maturity of the project. Furthermore, apart from the technological infrastructure, it is also important to consider the expected change in working methodologies due to automation and the guidelines for ensuring a successful implementation, as mentioned in Section 5.2.

The used case study organization acts as a BREEAM-NL consultant in multidisciplinary architecture, engineering, and construction (AEC) projects. It has been identified that this team is currently in the nascent stages of BIM adoption (A9, A10). The organization also specializes in mechanical, electrical, and plumbing (MEP) design, and the MEP team is also in the same organization as most of the projects dealt with by the BREEAM-NL team. Based on this information and the above-mentioned findings, the following recommendations are provided for the case study organization for the transition to BIM-enabled energy performance assessments:

- Identify target credits for automation: BIM offers varying levels of benefits depending on the requirements of the evaluation criteria. Therefore, before investing time and effort in developing software infrastructure for automating the assessment process, it is recommended to identify the credits that have the greatest impacts on design performance or are the most time-consuming ones. These credits will be taken further for automation.
- Identify the accountable stakeholders for information related to these credits. Making agreements on MEP-related information is relatively easier for this case, as it is an internal department. For credits that involve information related to other disciplines, these information requirements must be specified at the beginning of a project in the BIM execution plan.
- Aligning the input requirements of the automation tools with the existing data exchange formats and workflows wherever possible would help lead to a smoother adoption. Additionally, the organization should already start with developing guidelines on collaboration among teams.

6.2. Demonstration with One Selected Example Credit

This section follows the customized recommendations to the case study organization and the desired credits to be automated based on the desk study and interviews.

According to the current BIM adoption level of the organization and the organizational arrangement for the BREEAM-NL assessment process presented in the RACI matrix, ENE1, ENE4, and ENE5 have been identified as the target credits to use the BIM-based automation process. Of these three credits, ENE4 is chosen for the demonstration, as this one only requires MEP-related information, and in this organization, MEP designers are in the same team as the BREEAM-NL assessment members. This credit aims to promote the use of energy-efficient lighting fixtures in the exterior areas. The BREEAM-NL assessment guideline specifies three criteria for this credit:

- The luminous flux from the luminaires must be more than 65 lumen/watt and the maximum allowable specific power per lux illumination is 0.1 W (lux/m^2).
- Decorative or mood lighting with a non-renewable energy source is not allowed.
- Light fixtures must be equipped with automatic switching or dimming features.

An Autodesk REVIT-based plugin has been developed using REVIT API 2021 to automate the assessment for this credit using BIM data. Since no existing BIM tool has the BREEAM-NL requirements integrated in it, a platform that allows for the development of a custom plugin was needed, which is offered by REVIT API. This is also the software commonly used by both BREEAM-NL and MEP design teams (A7–A10) and, therefore, is considered the suitable choice for the practical implementation. The algorithm has made use of two built-in REVIT parameters namely luminous flux and wattage. In addition to this, three custom parameters have been defined for the lighting fixture family, namely exterior lighting, sensor connection, and mood lighting, as shown in Table 6. The lighting fixtures belonging to a zone have been grouped. Subsequently, spaces have been created matching the lighting group names. A custom parameter for spaces with the name "target illuminance" has been defined.

Table 6. Parameters used in REVIT ENE4 plugin.

Parameter Name	Parameter Type	Category	Value Type
Luminous flux	Built in	Lighting fixtures	Integer
Wattage	Built in	Lighting fixtures	Integer
Exterior lighting	Custom defined	Lighting fixtures	Y/N
Mood lighting	Custom defined	Lighting fixtures	Y/N
Sensor connection	Custom defined	Lighting fixtures	Y/N
Target illuminance (In Lux)	Custom defined	Spaces	Integer

The sequence of steps and decision gates used in the plugin is shown in Figure 3.

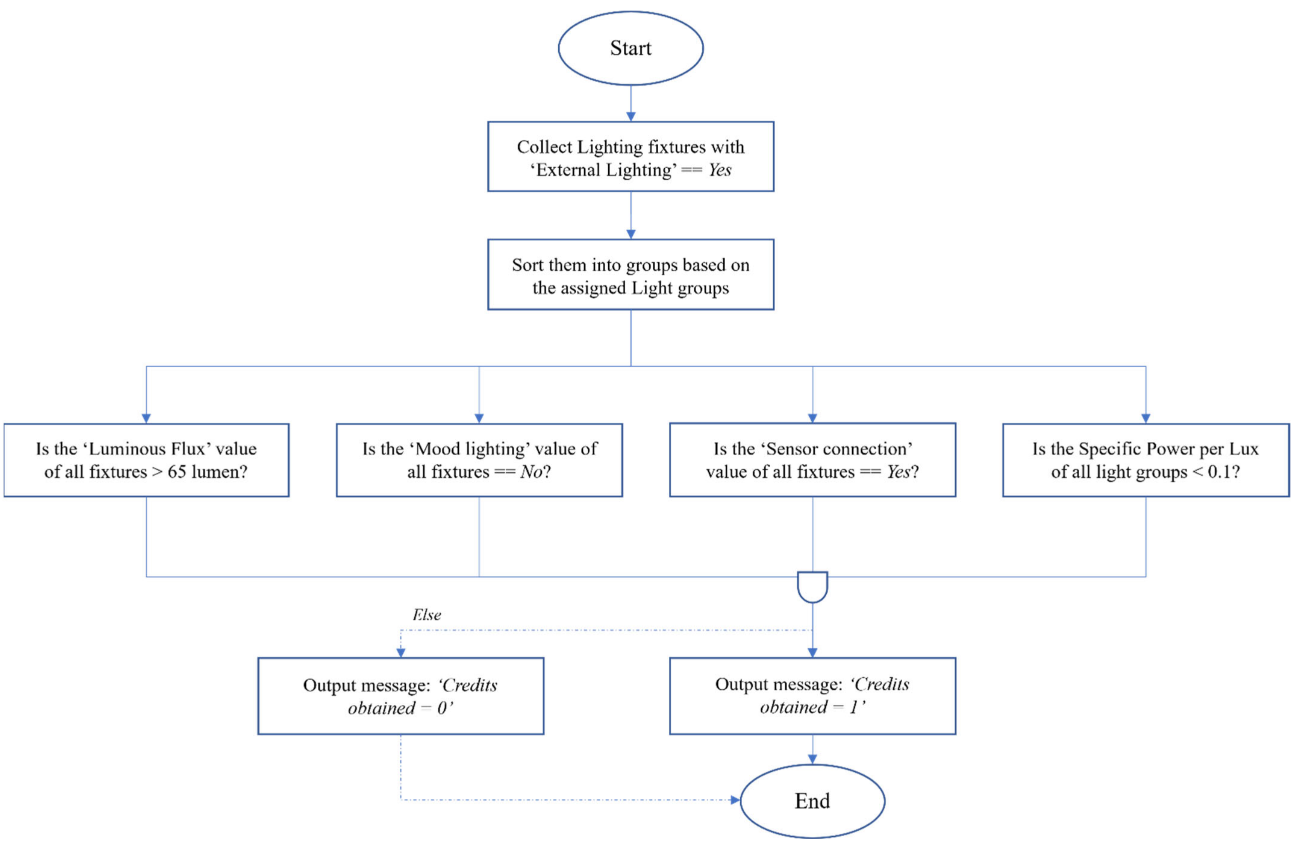

Figure 3. ENE4 plugin flowchart.

The plugin first filters through all the lighting fixtures present in the file using the parameter "exterior lighting". Then, the values given for luminous flux, mood lighting, and sensor connection are collected. Following this, specific power per lux calculation is performed for each lighting group using the properties of lighting fixtures and the area and target illuminance values of the associated space. Finally, if all the three BREEAM-NL criteria are met, the plugin provides a score of 1 point along with a report generated in CSV format.

The plugin has been tested on a sample REVIT model for the validity of the results (see Table 7 and Figure 4). The underlined parts indicate the not qualified criteria in the assessment. The algorithm displays a brief overview of the results in the task dialogue, and a detailed report is exported to a predefined location. This report can be used for documentation for evidence submission.

Table 7. Report generated by the plugin.

Group	Fixture Name	Mood Lighting	Sensor Connection	Luminous Flux	Watt	Light Number	Total Power	Area	Target Illuminance	Power Per Lux
Outdoor Zone 1	400-watt Halogen 2	Yes [1]	No [2]	4500	250	2	500			
Outdoor Zone 1								38	25	0.5263158
Outdoor Zone 2	Street Light-Sgl	No	Yes	5005	278	7	1946			
Outdoor Zone 2	400-watt Halogen 2	Yes [1]	No [2]	4500	250	1	250			
Outdoor Zone 2								64	13	2.639.423 [3]

[1] Outdoor lighting for decorative purposes leads to non-compliance and a score of 0. [2] Lack of automatic dimming or switching option leads to energy wastage and therefore is non-compliant with the credit requirements. Leads to a score of 0. [3] The maximum allowable specific power per lux illumination is 0.1 W (lux/m^2), and any value above this leads to a score of 0.

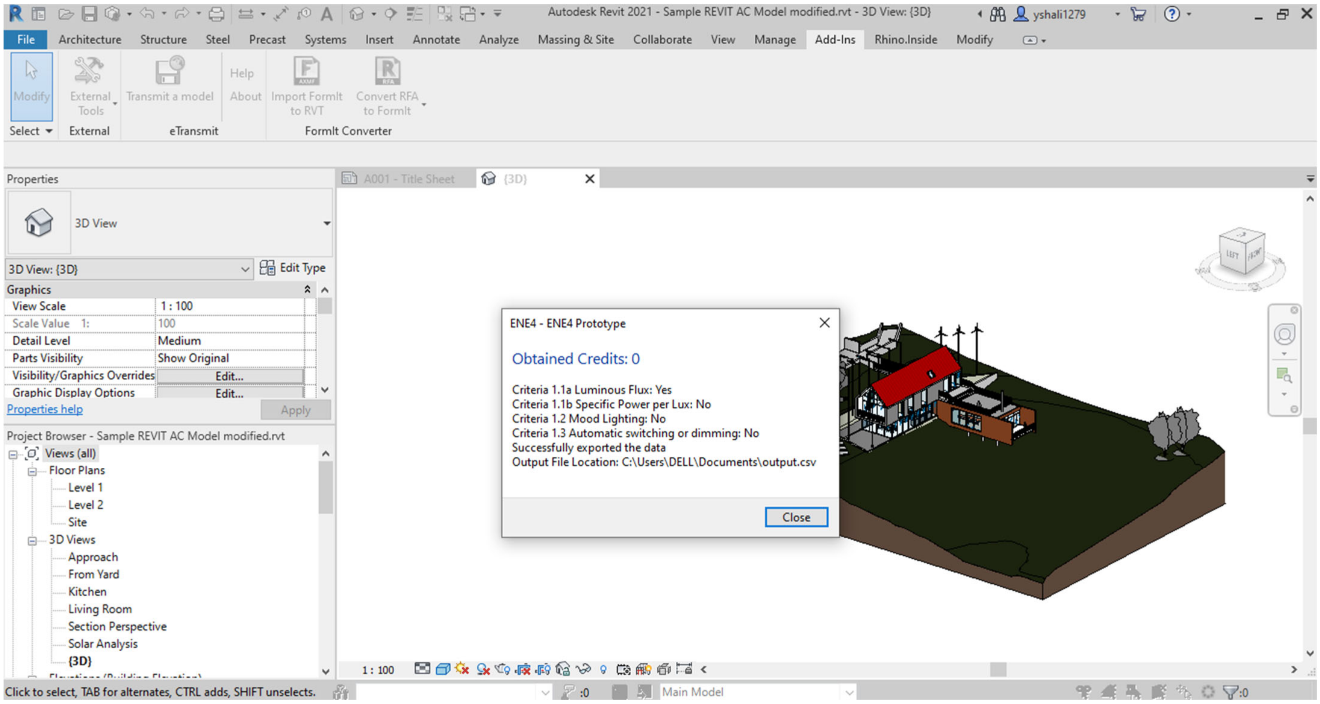

Figure 4. Screenshot of plugin results.

The results have been compared with the ones obtained through manual assessment methods. The reason for not using a real case study is that none of the existing models contained the information required for assessments. From the interviews, it has been found that it takes about 4 h for the BREEAM-NL team each time the assessment has to be made. Provided that the required information is in the BIM Models, this time can be reduced to just ten seconds, and the assessments can be made at any point in the design process.

7. Conclusions and Discussion

To accelerate building energy retrofits in the Netherlands, this study explores the potential of using BIM for automating energy performance evaluation for BREEAM-NL certification. The study used a case study organization to better understand the complexities of the assessment process and challenges faced in the industry concerning the application of BIM for building energy retrofitting evaluation.

This study combines literature review and practice research using semi-structured interviews to understand first the current workflow for BREEAM-NL energy assessment for the building retrofit process, and then, map this process with the BIM uses to identify possibilities for automation. A RACI matrix is developed to map different actors involved in the process, and potential impacts on actors involved are presented if automating energy credits evaluation will be implemented.

Based on the context in the case study organization and the BIM maturity of the sustainability team in the case study organization, customized recommendations are proposed for the implementation of BIM-based energy evaluations. It has been identified that in the context of the case study organization, which specializes in sustainability and MEP design consultancy, targeting ENE1, ENE4, and ENE5 credits for BIM-based automation is the most lucrative. A plugin is developed to demonstrate the automation process for the one identified example energy credit, and experts are used to validate the approach. The demonstration has revealed that the BIM-based automation can save a significant amount of time in the assessment process and can also improve the designs by providing an option of performance evaluation at any point in the design process.

The novelty of this study lies in the following aspects:

- Providing an overview for BIM-enabled automation potential for different energy credits in the BREEAM-NL assessment based on literature and practical interviews;
- Linking the changes in workflow due to BIM integration with the actors involved to identify potential impacts for each actor in different aspects;
- Offering a customized strategy to facilitate the implementation of BIM-based evaluations based on the contextual findings from the case study organization.

In countries such as the Netherlands, where a major chunk of the existing building stock is over 50 years old, renovation and retrofitting projects are becoming very essential to meet the energy requirements of the future. The benefits of using BIM on the sustainability performance evaluation of a building have been extensively discussed in the literature. BIM is known to improve the design process by allowing for a simultaneous evaluation of its performance and alternate solutions. However, the status of BIM-based sustainability and energy efficiency assessments as noticed in this case study team is lagging. BIM-based energy efficiency or sustainability evaluations for green certifications are not recognized as a common BIM use in the industry. This is reflected in the BIM execution plans, where neither the relevant BIM uses are identified nor the certification experts listed as relevant stakeholders. Based on the literature review, for the credits in the energy category of BREEAM-NL, intelligent data gathering through quantity take-offs, scheduling, performance analyses, and code compliance verification are the possible BIM uses. However, in practice, BIM models are being merely used as design references.

The findings of this study show that one of the primary reasons for this gap is the multidisciplinary nature of BREEAM-NL certification projects. Digitalization requires a considerable amount of preparatory efforts as it is, but even more so in the context of the transformation of intra-organizational processes. Development of automation infrastructure or digitalization strategies must bear this in mind. At an inter-organizational level, the transition to a BIM-based assessment process can be approached by identifying the credits that are most critical and relevant for the disciplinary specialization of the organization. The data requirements for automated assessments must be communicated to project stakeholders at the beginning of the design process. The automation process depends largely on the BIM maturity level of an organization, and therefore, context-specific strategies need to be taken. The process followed in this study can be used for other organizations to analyze their BIM possibilities and design digital transition strategies accordingly.

There are several limitations of this research that requires further exploration. First, the scope of the study is limited to design-phase assessments for BREEAM-NL certification. Further study can extend to other phases and see how to link lifecycle asset management to BIM use in energy performance evaluations. Second, this study builds on the hypothesis of the availability of a BIM model of the existing asset. The focus of the study lies in the applicability of BIM data for further analysis of building performance, and therefore, the process of data acquisition is not focused upon. For the existing building stock, not a lot of BIM models exist. A potential research direction could be integrating scan to BIM technologies and using voxelized geometries to automate building model processing process and generating suitable formats for BEM tools. Third, real projects are probably more complicated, which needs further research and validation to evaluate the efficiency gains with such a BIM-enabled automation process. Other types of categories in the BREEAM-NL assessment could be automated as well, and the overall efficiency gains could be calculated. Fourth, a holistic evaluation framework for stakeholders' involved could be developed to make better business decisions based on the data gathered such as efficiency gains and cost–benefit analysis. Fifth, as indicated in Section 5.2, the starting points for an organization to transit toward a BIM-based assessment process depends not only on technology readiness but also on the organizational business process and people involved. Therefore, a BIM maturity matrix that combines process, technology, and people aspects can be developed for different organizations to evaluate their BIM status and further design their digitalization strategies for not only BREEAM-NL but also other certification systems.

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