"The combined future of BIM and sustainability can help us move faster and more elegantly to a restored world and a healthy planet."

- Krygiel & Nies (2008)

BIM FOR BREEAM-NL ASSESSMENTS

An implementation strategy based on BIM Maturity

By Vyshali Simhachalam
MSC Graduation research | TU Delft

BIM for BREEAM-NL assessments: An implementation strategy based on BIM Maturity

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In partial fulfilment of the requirements for the degree of Master of Science
in Construction Management and Engineering at the Delft University of Technology

Publicly defended on 23.08.2021

In collaboration with

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Preface

After studying Architecture for five years, I found myself yearning for knowledge that went beyond a designer's desk. I wanted to learn how a fusion of technology and good management practices could address some of the pressing challenges faced in the building and construction industry. With this intent, I decided to move to the Netherlands two years ago to pursue a Master's degree in Construction Management & Engineering at TU Delft. And before you, lies the final result of this endeavour.

Before presenting the findings of this research project, I would like to take a moment to express my gratitude to the people that helped and guided me during this journey. First and foremost, I would like to thank my first supervisor Dr. Tong Wang for being a constant source of support and motivation in the past 7 months. Her enthusiasm towards the topic and positive encouragement in challenging times pushed me to perform better. I am grateful to my second supervisor, Dr. Yan Liu, for helping me refine the research problem and bringing in new theoretical perspectives to strengthen it further. His thorough review of all my report drafts helped me to pen down my thoughts better. I would also like to thank the chairman of my graduation committee, Dr. Hans Wamelink, for his constructive criticism and guidance. His feedback helped me recognize the weaker spots of my work and provided opportunities for further improvement.

This thesis project is a combination of two topics that I am very passionate about: BIM and sustainability. I was extremely fortunate to have found the perfect opportunity to combine them both. For this, I have my colleagues at Deerns to thank for. My supervisors from the company, Lorena Montenegro and Geert van Gorp, brought unique perspectives from each of these topics that helped broaden my understanding of the research problem. I am very grateful for the time and energy they invested in this project and look forward to further collaboration in the coming months.

I come from humble beginnings. Growing up, moving abroad for higher education was not something I even dreamed of. So it goes without saying that everything I accomplished so far is because of my family. I am forever indebted to my parents for their unending love and support, and my sister for being my partner in everything. Lastly, I would like to thank my friends for all the joy and comfort they provided during the challenging times COVID has presented in the past year. I could not have asked for a better support system.

Wishing you a pleasant reading!

Vyshali Simhachalam
August, 2021

Executive Summary

As climate change concerns increase, more and more clients are aiming for higher sustainability ratings for their properties. Green building rating systems cover a wide range of topics, divided into performance metrics in the form of 'credits'. Having an idea of the performance of the design against these metrics in early stages will provide more room for design optimization. However in practice, these assessments are done at the end of the design phase due to the fragmented nature of information distribution in AEC projects. The application of Building Information Modeling provides an opportunity for automated green building assessments and real-time feedback. Quite a few authors have discussed the technical possibilities of automated BIM-based Green Building Assessments (GBA) in the last ten years. However, automated sustainability compliance verification is not yet a very common BIM application in practice.

This thesis project aims to address this research gap, by taking a closer look into practice to identify the barriers that are hindering the adoption of BIM for BREEAM-NL assessments and proposing a strategy to further the utilization of BIM for this purpose. To achieve this, the main research question for this graduation project has been formulated in the following way:

"How can the use of BIM for BREEAM-NL assessments be accelerated in practice?"

This is further divided into the following five sub-questions:

SQ 1. Theoretically, how can BIM help in the assessment process of BREEAM-NL?
SQ 2. To what extent BIM is currently being used in BREEAM-NL assessment process?
SQ 3. How does the industry situation compare to the promised potential of BIM for green building assessments? What are the reasons for the gap?
SQ 4. How can project teams start bridging this gap and make the best use of BIM for BREEAM-NL?
SQ 5. How does the proposed strategy help BREEAM-NL project teams?

The project was done in collaboration with a Dutch engineering consultancy named Deerns B.V. in the Hague. Since the project aims to answer a practice-oriented question using the knowledge base from scientific literature, a design science research framework was deemed a suitable research methodology. Based on this framework, the study is divided into five phases: Literature review, Insights from practice, BIM implementation strategy design, Case study recommendations and Validation.

Since BREEAM-NL assessment guideline covers a wide range of topics, the scope of this project is limited to Energy and Material category credits due to the time constraints. BREEAM-NL New Construction and Renovation, 2014 v2 is the chosen assessment guideline for investigation. However, the methodology adopted for the study can be extended to other versions of the rating system.

Advantages of BIM for BREEAM-NL

Scientific literature available on the topic of BIM based Green Building Assessments was reviewed to identify the advantages and limitations of BIM for BREAAM-NL assessments. The results are reported in Chapter 3. For the BREEAM-NL expert team, the relevant BIM uses primarily relate to gathering necessary information from BIM Models and using that for performance analyses and code validation. The exact relationship between BIM uses and each of the BREEAM-NL credits depends upon the nature of the input requirements. In Energy and Material categories of BREEAM-NL, that is worth a maximum of 46 points in total, the calculation of 9% of the credit points cannot be achieved using BIM. The credits

with input information coming from BIM Models, the assessments can be fully automated. For the credits that require input from performance analysis tools, the assessments can be partially automated due to the technological limitations for data exchanges.

Current status of BIM application for BREEAM-NL assessments

Currently, in the context of BREEAM-NL assessments, BIM models are not actively used. Information required for the calculations associated with BREEAM-NL credits are obtained primarily from 2D drawings. For most credits, the project team uses excel tools either made by them or provided by the DGBC for assessments. Gathering the input required for these tools is often the most challenging part. Although 3D models & 2D drawings are often shared in a Common Data Environment, the information is unorganized and therefore, email based communication is opted for information requests.

The reasons for the gap between possible and actual level of BIM use for BREEAM-NL assessments are three-fold: 1) On the technological front, the lack of a commercial software that can directly automate assessments and the poor interoperability between the BIM authoring and performance analysis tools are hindering BIM based GBA in practice. 2) At the BREEAM-NL team level, there is a lack of awareness about the possibilities of BIM and how to use them in practice. 3) At a project level, the dependency with the external stakeholders for inputs for assessments and aligning the information exchange formats with the requirements of the BIM based automation tools is challenging.

In addition, some constraints that restrict or limit the implementation of BIM for GBA were also found. First, considering the effort required to switch to a BIM-based workflow, the profitability of this endeavour is uncertain in small-scale projects. Due to the time and budget limitations in such projects, the front-end efforts required for automated assessments do not always outweigh its benefits. To add to this, the cooperation from external stakeholders (design teams) can only be ensured with the support of the client. Further, if the design teams are operating on lower maturity levels, the BIM models do not contain adequate information for sustainability assessments. Therefore, the scale of the project, support from the client and BIM maturity levels are the constraints for the implementation of BIM-based GBA. More information on the interview results can be found in Chapter 4.

BIM Implementation strategy

These findings reinforce the argument that BIM is more than just technology, and a successful implementation strategy must also consider the other BIM fields: Process and Policy. Further, not every team can take advantage of all the relevant BIM uses as the possibility of their application in practice is governed by the level of BIM maturity a team operates at. The success of a BIM-based GBA is only as good as the information contained in the BIM models, and its level of applicability proportionally increases with the BIM maturity. Therefore, to reach the ultimate vision of a fully automated BIM-based automated assessments for BREEAM-NL or any green building certification for that matter, incremental changes in Technology, Policy and Process fields are required.

Based on these findings, this study proposes a BIM Maturity Matrix for BREEAM-NL assessments that can help the project teams identify where they currently stand and how they can transition towards a more automated, BIM-based assessment process. Previous scholarly works on BIM Maturity models such as Succar et al., (2009), Siebelink et al., (2018) and Liang et al., (2016) were used as a reference to identify the applicable sub-criteria for BREEAM-NL assessments across each BIM field. The results are shown in Table A (Elaborated in Chapter 5). Using this matrix, project teams and organizations can have a clear idea of where they stand in all the three fields and therefore, what the immediate next steps are in the transition to a BIM-based BREEAM-NL assessment. It must be noted that these stages do not represent the status of organization's overall BIM maturity, but only specific to BREEAM-NL assessments.

Table A: BIM Maturity Matrix for BREEAM-NL

Step set		Pre-BIM	Stage 1: Manual assessment	Stage 2: Partially automated assessment	Stage 3: Highly automated assessments
BIM Field	**Sub-domain**				
Technology	Model content (T1)	2D	Mix of 2D & 3D	Detailed 3D design models	Detailed 3D design & construction models
	Hardware support (T2)	NR	Limited hardware support	Sufficient hardware support	Powerful hardware systems
	Software tools (T3)	NR	3D model viewing software programs	Tools for partial automation	Tools for high automation
Process	Information exchange (Pr1)	Paper based	Electronic file based	Federated models in CDE	Integrated models on a cloud platform
	Management support for BIM (Pr3)	NR	BIM Vision for BREEAM-NL projects	Small scale pilot projects	Large scale implementation support
	BIM Training (Po3)	NR	Ad-hoc	Extensive BIM training for target personnel	Structured BIM training for the entire team
	BIM roles (Pr5)	NR	Ad-hoc	Information manager appointed	Internal BIM roles are defined
Policy	BEP	NR	No involvement from BREEAM-NL team	Low level details	Highly detailed
	Contractual (Po2)	NR	Not BIM related	BIM Protocol	Reward mechanisms & risk allocations
	Deliverables (Pr4)	NR	No BIM deliverables for BREEAM-NL	BIM deliverables for pilot credits	Specific BIM deliverables for all credits

NR = Not Relevant for this stage

Recommendations for the case study team

Based on the results from the initial interviews, the current maturity stage of the BREEAM-NL project team was assessed. It was found that overall, the team stands at BIM stage 1. Based on these results, immediate next step for the case study company is to initiate the transition to Stage 2. This involves a set of actions across all the three domains of Technology, Policy and Process. The recommendations proposed for the case study team are shown in Figure A. The recommendations are divided into four parts: 1) Preparatory tasks to be done by the BREEAM-NL team before initiating the implementation process 2) Technology related tasks to develop the infrastructure for automation. This can be done with the help of the organization's BIM department. 3) Process-related tasks for integrating BIM within the workflow. These are to be carried out at the team level. And lastly, 4) Policy-related tasks for accommodating the BIM based workflow through agreements with external stakeholders and clients.

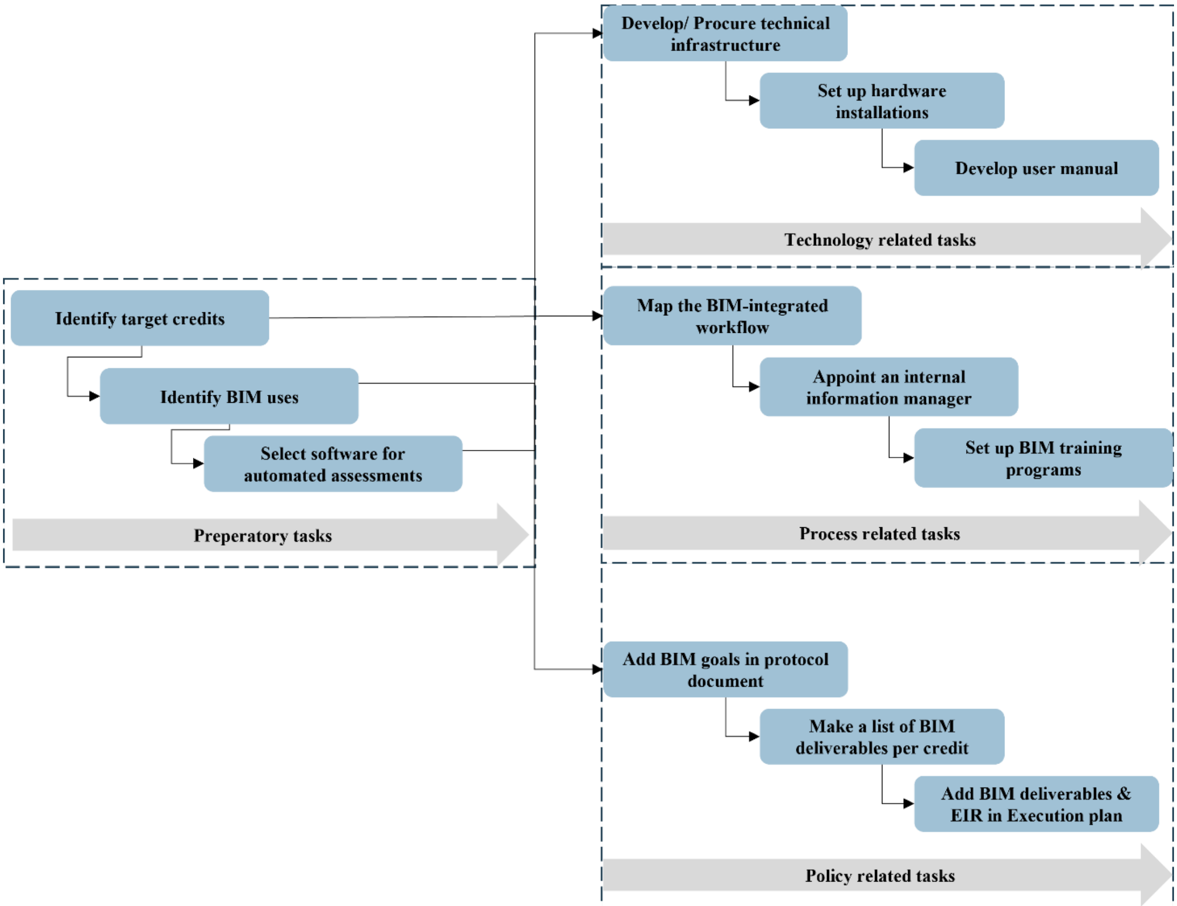

Figure A: Recommendations for the case study team

The recommendations proposed are generalized, and meant for the whole certification scheme. To elaborate further on what this would look like on concrete terms, MAT05 credit was chosen as an example. The reason for choosing this particular credit is that it is one of the simpler credits with regards to the assessment procedure, yet very time consuming. This is a good example to demonstrate how BIM can make some mundane, repetitive tasks more efficient through automation. Using REVIT API, a plug-in was developed that can automate the MAT5 calculation. Associated process and policy level changes and action steps are also discussed. The recommendations are elaborated in Chapter 6.

The prototype was tested on the office part of an industrial project handled by the case study team. It was found that the results produced by the Plug-in matched with the results from the manual assessment method and reduced the assessment time from a minimum of 2 hours to 30 seconds. For more details about the prototype, refer to Chapter 7.

Following this, three BREEAM-NL experts and 2 BIM experts were presented the results of the research project and asked their opinion on the feasibility of implementation and usefulness in practice. The experts expressed that from an internal (organizational) perspective, the recommendations are feasible with regards to the efforts that are required for this transition. From an external perspective, they felt that the recommendations provided address the issues of interdependency in information management, but implementation would require support from the client and adequate project budget. Overall, they expressed that proceeding with this implementation plan could make the BREEAM-NL assessment process more efficient and faster.

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Abbreviations

- AEC - Architecture, Engineering &Construction
- BE - Bouwphysca & Energie
- BIM - Building Information Modeling
- BEM - Building Energy Modeling
- BEP- BIM Execution Plan
- BPM – Building Performance Modeling
- BPMN – Business Process Model and Notation
- BMS – Building Management System
- BRE- Building Research Establishment
- BREEAM - Building Research Establishment's Environmental Assessment Method
- CDE – Common Data Environment
- DGBC - Dutch Green Building Council
- EPC - Energy Performance Coefficient
- ENE - Energy
- IFC – Industry Foundation Classes
- IPD – Integrated Project Delivery
- IDM – Information Delivery Manual
- GBA - Green Building Assessment
- GIS - Geographic Information System
- IGBPM - Integrated Green BIM Process Map
- LEED - Leadership in Energy and Environmental Design
- LOD – Level of Detail
- MAT - Material
- MVD – Model View Definition
- NMD - National Material Database
- WGBC – World Green Building Council

Glossary

- **BIM:** A set of interacting policies, processes and technologies that generate a methodology to manage the essential building design and project data in a digital format throughout the building's lifecycle (Penttila, 2006 as cited in Succar et al., 2012).

- **BIM Execution plan (BEP):** It is a document that explains how the information requirements set out by the client are met with by project delivery team. There maybe two versions of a BEP: 1) The one submitted by each project stakeholder individually in the pre-tender phase and 2) A joint BEP formulated together by all the actors in the project delivery team post appointment. (*BIM Dictionary*, 2021)

- **BIM Fields:** The three domains of BIM activity i.e., Technology, Process and Policy are termed as BIM fields. Technology refers to the practical application of scientific knowledge through software, hardware and network systems that improve the efficiency of AEC projects. Process refers to the ordering of various project activities, defining inputs, outputs and responsibilities of actors. Policy refers to the principles, rules and protocols that guide the project activities (Succar, 2009).

- **BIM Maturity models:** Maturity models delineate the stages of BIM implementation based on the tools used, accuracy of modeling and the resulting information exchanges. They serve as useful frameworks to measure and manage the progress of BIM proficiency across an organization or team (Sacks et al., 2018).

- **BIM Protocol:** The term BIM protocol may refer to prescriptive and optional guides to attain certain BIM goals or mandatory guidelines dictated by an authority. In this report, a 'BIM protocol' refers corresponds to the following definition:
  A contractual document between the client and project consultants defining the terms and conditions regarding the application of BIM in a project and the associated deliverables to the client. It is a formal documentation of BIM based communication and exchange methods and final deliverables.

- **BREEAM-NL assessor:** A qualified professional in relation to BREEAM-NL, working for a licensed organisation, that is ultimately responsible for assessing the evidence submitted by the project team and awarding a rating (Dutch Green Building Council, 2009).

- **BREEAM-NL Expert:** Qualified process manager and content expert with regards to BREEAM-NL requirements. A training program prescribed by the BRE and DGBC needs to be completed to attain the title of a BREEAM-NL Expert. Experts assist the clients in the BREEAM-NL certificate acquisition process (Dutch Green Building Council, 2009).

- **BREEAM-NL Expert team/ BREEAM-NL team:** In this report the term 'BREEAM-NL Expert team'/ 'BREEAM-NL team' will be used to refer to the set of stakeholders involved in making the sustainability assessments and managing associated processes to acquire a BREEAM-NL certification.

- **BREEAM-NL credits:** The sub-topics of each of the categories of BREEAM-NL assessment guideline are termed as credits. Every credit has a defined sustainability objective, criteria for fulfilment and achievable number of points (Dutch Green Building Council, 2014).

- **Common Data Environment (CDE):** A central data repository for a project accessible to all project teams. All stakeholders can retrieve the required input data from a CDE and also store their discipline specific outputs. Standard procedures and techniques are defined to store and access information from a CDE (Borrmann et al., 2018).

- **'Category' of BREEAM credits:** The BREEAM certification credits are divided into nine groups on the basis of the sustainability topic they deal with. These groups are called categories. The categories of a BREEAM certification are: Management, Health, Energy, Transport, Water, Materials, Waste, Land use & Ecology, Pollution (Dutch Green Building Council, 2014).

- **Green Building Assessments (GBA):** In this thesis report, the term Green Building Assessments (GBA) refers to the following definition: The process of evaluating the performance of a building and comparing it against green certification standards in order to assess the level of compliance with the green certification requirements.

- **Information Delivery Manual (IDM):** A document that defines the series of processes undertaken in a project, the associated information requirements and contents of the BIM model (buildingSMART®International, 2010).

- **Model view Definition (MVD):** A selection of entities from the overall IFC Schema that is used to facilitate a particular use or workflow, such as MVDS for exporting BIM data to performance analysis tools (buildingSMART®International, 2010).

- **'Type' of BREEAM credits:** In this thesis report, a *Type* of BREEAM-NL credit refers to the way they are associated with BIM.
  Type 1 credits can be assessed solely based on the inputs from BIM authoring models
  Type 2 credits can be assessed based on the results from performance models
  Type 3 credits can be assessed used information from BIM models plus and external database
  Type 4 credits cannot be assessed automatically using BIM and require human input.

Chapter 1

Introduction

The aim of this chapter is to introduce the research topic and the objectives of this study. The chapter is divided into five sections: First, some background to the research subject is provided; Second, the problem that this study aims to address is stated, along with the relevance it bears for the industry and academia; Third, the research scope and its boundaries are stated; Fourth, the research questions are defined and finally, the outline of this thesis report is summarized for the benefit of the reader.

1.1 Background

After contesting the consequences of exponential resource consumption and human emissions of greenhouse gases for decades, the phenomenon of climate change has started to be widely accepted since the 1990s. The substantial contribution to the global resource and energy consumptions made by the built environment has shed light upon the need for a sustainable movement within the Architecture, Engineering and Construction (AEC) industry and has started the conversation of green buildings going. World Green Building Council (WGBC) defines a green building as '*a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment.'* (WGBC, 2017).

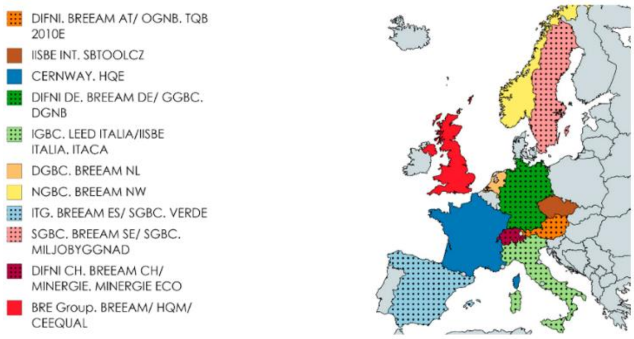
This paradigm shift in the industry led to the evolution of building codes and guidelines to enable and evaluate sustainable developments. Green building councils were formed with an aim to steer the construction industry towards a more sustainable future through their green building rating tools (Ade & Rehm, 2019). Since its inception by the Building Research Establishment's Environmental Assessment Method (BREEAM) in 1990, green building certifications have spurred interest and growing demand in the domain of sustainable design and construction.

Green building certifications in the Netherlands

Currently it is estimated that there are nearly 600 green certifications in the world (Vierra, 2019), BREEAM and LEED (Leadership in Energy and Environmental Design) being the predominantly used ones (Raouf & Al-Ghamdi, 2018). Gluszak (2015) and Sánchez Cordero et al., (2019) analysed the competitive position of various green certification systems in Europe and the results from both studies indicate that in the Dutch construction industry, BREEAM is the most widely accepted choice of environmental assessment (See Figure 1 & 2).

Its demand has been increasing even more since the Dutch Green Building Council (DGBC) adopted and developed a country specific version of the certification – BREEAM-NL in 2009. The reason for this increasing preference for BREEAM-NL over LEED could be because several requirements that are mandated by the Dutch legislation such as the Energy Performance Coefficient (EPC) calculation are embedded within the BREEAM-NL certification system. Whereas LEED certification is based on the American standards such as ASHRAE.

An analysis of the BREEAM-NL trends in the Dutch real estate market performed by DGBC in 2020 indicated that the total BREEAM-NL certified area as well as the number of professionals and students in the Netherlands investing in the certification training has been steadily increasing. Apart from the obvious benefits such as positive impact on environment, lower operational costs and financial subsidies available for sustainable developments, an increase in property values is also noticed in association with BREEAM-NL labels. Study on the relationship between BREEAM-NL and commercial property values in the Netherlands by Van der Zijden (2017) showed that the level of sustainability has a direct positive relationship between the expected rent premium. The study concluded that a potential profit of 13.89 percent can be made through investment in sustainability certifications. This further drives the clients' motivation to pursue higher ratings in this certification and therefore, the number of projects aiming for this certification are only expected to increase in the future (Holtermans & Kok, 2018). Since this thesis project is carried out in the Dutch market, BREEAM-NL certification is of particular interest to this study.



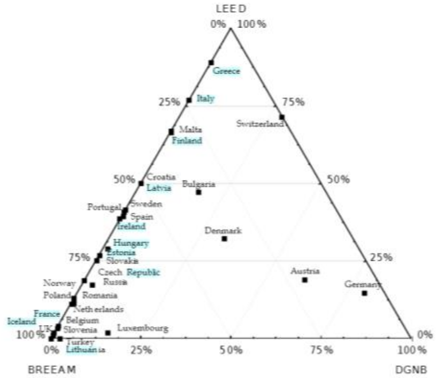


Figure 1 Most popular green building certifications in European countries (Sánchez Cordero et al., 2019)
Figure 2 Competitive position of DGNB, BREEAM & LEED in European countries (Gluszak,2015)

1.2 Problem definition

Green building rating systems break down the complex subject of sustainability into categories such as Management, Health, Energy etc., and provide a program of requirements for each of these sub-topics on the basis of a 'credit-list'. If the design and construction project team can demonstrate compliance with these credit requirements, points can be awarded. Based on the total number of points achieved by the project, its overall rating and the level of certification is determined.

In order to get the final certificate, the project team has to submit documents of evidence that demonstrate how the requirement criteria for each credit has been met with. This entire process is time-consuming and laborious because it requires large amounts of interdisciplinary information that is distributed between several different stakeholders. Managing this chaos in the distribution of information is one of the biggest challenges of Green Building Assessments (GBA) (Wu & Issa, 2013). Traditional method of green building assessments is manual and therefore, it is not only time-consuming but also error-prone (Jiang et al., 2018). A more efficient and intelligent way of data acquisition and assessment system can greatly benefit project teams in achieving green certifications.

Some of the solutions proposed to address these challenges in the green building certification process include Integrated Project Delivery (IPD) methods, managerial solutions such as green and lean project management practices (Lapinski et al., 2005 & Blomfield, 2011), changes in project contracting to promote accountability (Robichaud & Anantatmula, 2011) and lastly, the use of Building Information Modeling (BIM) (Azhar et al., 2011; Lu et al., 2017; Ismail et al., 2019 etc.) The focus of this study is on BIM as a potential solution for streamlining BREEAM-NL assessment process.

The use of BIM can benefit the BREEAM-NL assessment process in the following ways: 1) By integrating the fragmented data sources in AEC projects through central information models, it makes the process of gathering the required information for BREEAM-NL assessments more efficient (Krygiel & Nies, 2008) 2) Through the facilitation of a collaborative working environment and real-time information sharing. it will ensure that the assessment team has access to up-to-date, accurate information which in turn, will reduce re-work (Carvalho et al., 2020). 3) And finally, the possibility of automating the assessment process is the biggest advantage BIM has to offer for GBA process, as it will significantly reduce the amount of time that goes into this process as well as the possibility of errors in calculation.

The synergy between BIM and Green building assessments can be investigated in three fields: 1) *Technical*- Mapping BIM capabilities to the needs of Green building rating requirements and developing tools for automating the assessment and documentation tasks; 2) *Process*- Understanding the process workflow, roles and responsibilities of team members to identify opportunities and strategies for BIM implementation; 3) *Policy*- Investigating the protocols and guidelines required to facilitate the implementation of BIM for green building assessments on technical and process levels.

Previous research on this topic heavily focussed on the technology field (Lu et al., 2017). In the past ten years, several works such as Azhar et al., (2011), Wu and Issa (2011 & 2012), Jalaei and Jrade (2014 & 2015), Nguyen at al., (2016), Ilhan and Yaman (2016), Zhang et al., (2019) etc., have explored ways of integrating BIM in the green building assessment process using different approaches, different software tools and at varying maturity levels. While the technical possibilities of BIM-based GBA have been adequately researched upon (although there is still scope for improvement), the know-how on how to align sustainability goals with BIM-based collaborative processes is still missing (Zanni et al., 2014). This is also reflected in practice where BIM is not yet being used for green building assessments in the way it has been depicted in the literature (Alsehrawy et al., 2020).

Legal and policy related issues such as changes in contracts to facilitate BIM based GBA, information ownership and standardised division of roles and responsibilities have not been discussed in the existing literature. Mohamed et al., (2018) concluded that to bridge the gap between BIM and sustainability, the current state of BIM-based sustainability applications and associated challenges must be investigated through field work in further research. Further, determining how organizations and project teams can make this transition to a more automated, BIM-based workflow for green building assessments is also needed.

As shown in Figure 3, this thesis project aims to address this research gap, by taking a closer look into practice to identify the barriers that are hindering the adoption of BIM for BREEAM-NL assessments and proposing a strategy to further the utilization of BIM for this purpose.

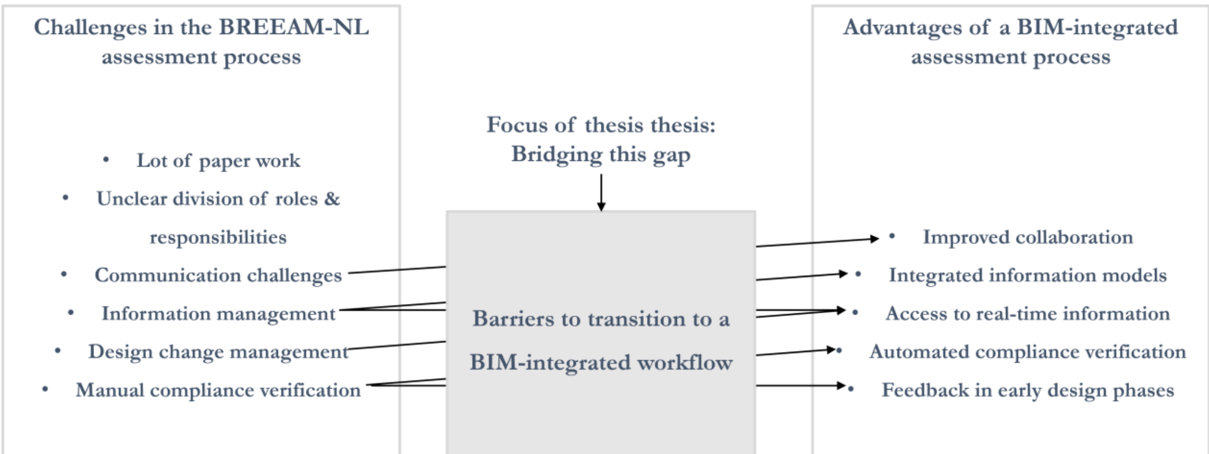


Figure 3 Focus of the research (Own image)

Scientific relevance

As mentioned in the previous section, the discussion on BIM uses for green building assessments have mostly been focusing on the technical aspects so far. While some studies such as Wu & Issa (2013) & Zanni et al., (2014) took a process perspective to explore the synergies between BIM & green building design process in general, no attention has been paid to investigate the implementation aspects of BIM-based Green Building Assessments. By taking a practice-oriented research approach, this graduation project aims to provide insights on the actual status of BIM adoption for BREEAM-NL assessments and strategies to further the utilization of BIM in this domain. To the best of the author's knowledge, this line of investigation has not been done before, and therefore, is of value to the scientific community concerned with research on this topic.

Practical relevance for Deerns B.V.

This research project has been carried out at the head office of Deerns B.V. located in the Hague, within the Building Physics & Energy (BE) department. Deerns is an internationally established engineering company specializing in building physics, sustainability, installation technology and energy transition. Through their in-house experts, they offer advice for achieving specific sustainability ambitions such as BREEAM, LEED or WELL certifications, as well as services for guidance and supervision throughout the certification process.

The BE team at Deerns has recently initiated an internal project to standardize the documentation templates and workflows of BREEAM-NL projects. The final phase of this project aims to identify ways to better integrate BREEAM-NL requirements with BIM protocols so that the information required to perform BREEAM-NL assessments is readily available in the BIM models shared by the external stakeholders. This clear link between BIM data and credit requirements can save the BE team significant amount of time that goes into requesting this information from each stakeholder, and hence, the interest from the company in this research project.

The results, however, can be useful to any organization/ team that intends to shift to a BIM-based workflow for BREEAM-NL assessments.

1.3 Research scope and boundaries

This graduation project has been done in partial fulfilment for the requirements of the Master of Science degree in Construction Management & Engineering at TU Delft. The project has a weight of 32 ECTS and its intended duration is 6-7 months. Keeping this time constraint in mind, research boundaries have been demarcated to allow for an in-depth research within a specified boundary. The boundaries of this thesis work are as follows:

1. **BREEAM-NL**: In order to map the relationship between BIM capabilities and green certification requirements, the scope had to be narrowed down to one green building rating system. Since the project has been done in the context of Dutch construction industry, and for the reasons mentioned in section 1.1, BREEAM-NL is the chosen certification system.

2. **New Construction**: BREEAM-NL has four hallmarks: New construction, In-Use, Refurbishment & Fit-out, Area development & Infrastructure.
   The research project focusses on buildings as the adoption of BIM practices in infrastructure and area development projects is lagging behind in comparison to building sector. Research on aligning sustainability goals with BIM requires some degree of BIM-based design practices to begin with. New construction is chosen over In-Use, Refurbishment & Fit-out as in the latter categories, the

existence of BIM models of the projects is not guaranteed, and that adds another layer of complexity to the research, which is not the main focus.

3. **Office Buildings**: Some variations in the BREEAM-NL requirements exist based on the use type/ function of the building. For this research, the guideline for offices is taken into consideration as it is one of the most common project types that go for BREEAM-NL rating (CBRE, 2018). *However, in theory, the approach adopted will be applicable to other building functions as well.*

4. **Energy & Materials**: BREEAM-NL consists of ten categories of credits namely Management, Health, Energy, Transport, Water, Materials, Waste, Land use and Ecology, and Pollution. Literature review of the feasibility of BIM-based sustainability assessment methods indicate that Energy and Material related categories have the highest potential for integration with BIM (Carvalho et al., 2020). Therefore, these credits will be studied in detail for this project.

1.4 Objective & research questions

The objective of this research is two-fold: 1) First, to investigate the current status of BIM implementation for BREEAM-NL assessments and how it compares with the literature findings; 2) To design a strategy to facilitate the transition to a BIM-based process for BREEAM-NL assessments. This will help in bridging the gap between industry and scientific literature surrounding the topic of BIM-based assessments for green building certifications. In order to fulfil this research objective, the main research question for this graduation project has been formulated in the following way:

"How can the use of BIM for BREEAM-NL assessments be accelerated in practice?"

This is further divided into the following five sub-questions:

SQ 1. Theoretically, how can BIM help in the assessment process of BREEAM-NL?
SQ 2. To what extent BIM is currently being used in BREEAM-NL assessment process?
SQ 3. How does the industry situation compare to the promised potential of BIM for green building assessments? What are the reasons for the gap?
SQ 4. How can project teams start bridging this gap and make the best use of BIM for BREEAM-NL?
SQ 5. How does the proposed strategy help BREEAM-NL project teams?

Answering each of these sub-questions will provide a useful piece of information that will ultimately help in answering the main research question.

1.5 Thesis report outline

Chapter 2 of this report describes the research methodology adopted. Chapter 3 will provide the theoretical knowledge on BIM and its relation to Green Building Assessments, an introduction to BREEAM-NL rating system and how the credits in Energy and Material categories relate to BIM. Chapter 4 describes the BREEAM-NL assessment process, the challenges faced and the barriers to BIM adoption. Chapter 5 describes the strategy this thesis proposes in response to the challenges in BREEAM-NL certification process in the form of a BIM-GBA Maturity matrix. Chapter 6 will demonstrate the application of the proposed strategy on case study organization and discuss the recommendations proposed for BIM implementation. Chapter 7 is dedicated for verification and validation of the thesis results. Chapter 8 will discuss the results of this research project, its limitations, recommendations for further research and finally, the personal reflections of the author.

Chapter 2

Methodology

This chapter describes the design of this research project- the methodology adopted and the reasoning behind it, phasing of various research steps, the relation between research steps and the research questions defined in Chapter 1.

2.1 Design Science Research Framework

Design science research (DSR) is fundamentally a problem-solving, solution-oriented paradigm (Brocke et al., 2020) aimed at improving human performance (van Aken, 2005). It is pragmatic in nature, offering a better way to connect real world problems with academic research (Romero, 2017). The central objective of a design science research is to understand the field problems on a topic and develop knowledge that can be used by the professionals to solve these problems (van Aken, 2005).

The key elements of a design science research framework are environment, knowledge base and design (Figure 4). Environment refers to the problem setting, comprised of organizations, people and existing tools, methods and workflows. This forms the source information for the identification of problems, needs, opportunities and goals. Knowledge base refers to the existing body of knowledge on the topic that provides foundational theories and methodologies to propose solutions that address the needs identified from the environment.

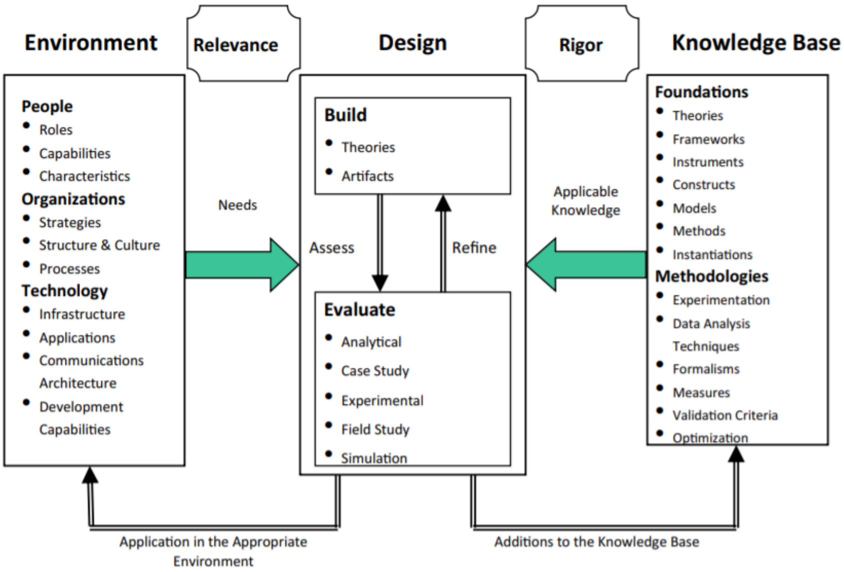


Figure 4 Design Science Research Framework (Brocke et al., 2020)

As noted in Romero (2017), the interaction between academic research and professional practice in the AEC industry is quite limited. The same applies to the topic of using BIM for analyses required by green certification systems. The design science research approach allows for a better connection between academic research and industry needs. This aligns with the aim of this research project and therefore, is the chosen methodology.

2.2 Research design

Based on the design research framework, this research study is divided into five phases: Literature review, Insights from practice, BIM implementation strategy design, Case study recommendations and Validation. Each phase corresponds to a part of the DSR framework as shown in Figure 5.

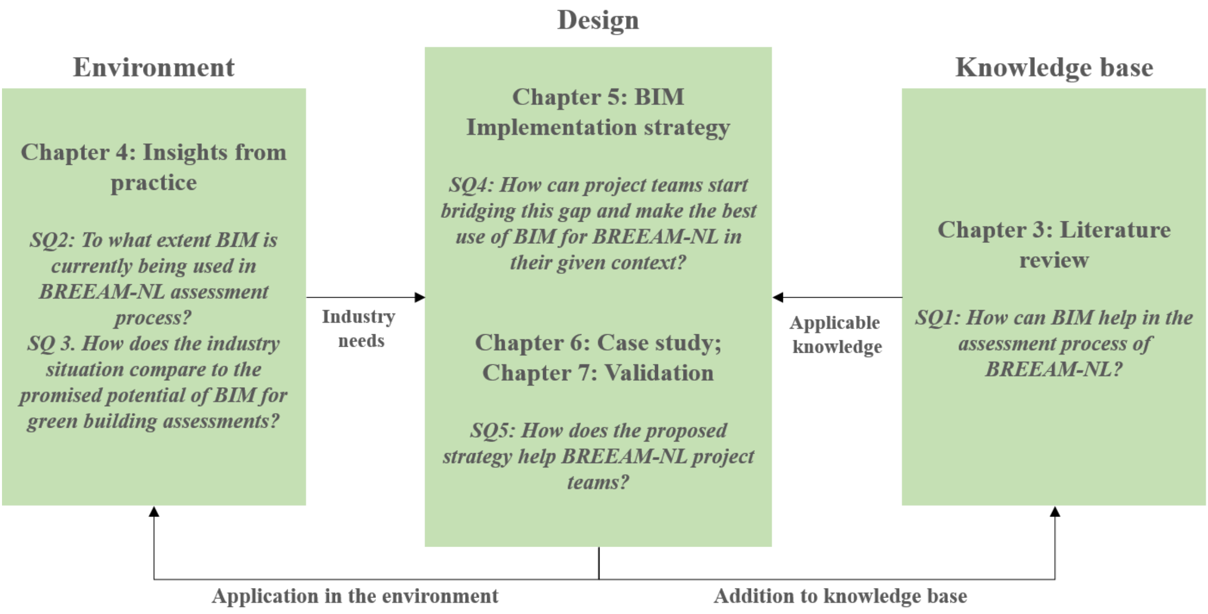


Figure 5 Research design (Own image)

1. **Literature review :** The applicable knowledge for this research project relates to the concepts of BIM, and its applicability for BREEAM-NL assessments. To gather this information, scientific literature focussing on possibilities and challenges of Green BIM, the automation of GBA, and integrating BIM based workflows in the design and construction processes were reviewed. Information related to the characteristics of the BREEAM-NL certification, the sustainability topics covered in the rating system, the scoring methodology were gathered from the publications by the DGBC. The results, along with the answer to the first sub-question are presented in Chapter 3.

2. **Insights from practice:** To establish a link between theory and practice, case study research was performed in collaboration with the Dutch engineering consultancy – Deerns. Semi-structured interviews were conducted with industry practitioners to identify the nature of the assessment process for obtaining a BREEAM-NL certification, challenges involved and the needs of the industry. These interview results also shed light upon the current status of BIM implementation for BREEAM-NL assessments, barriers to further utilization, and how the situation in the industry compares to that described in scientific literature. Chapter 4 includes the interview results as well as answers to the second and third sub-questions of this research.

3. **BIM Implementation strategy (Design):** This step refers to the design of a solution/ strategy/ artefact in response to the practical needs identified from the industry environment. Results from the first two steps laid the theoretical foundation upon which a strategy was built for aiding practitioners in utilizing BIM for BREEAM-NL assessments. This is discussed in detail in Chapter 5. The answer to the fourth sub-question is also provided.

4. **Case study:** This step corresponds to the demonstration of the design outcome of a design science research. The strategy design in Step 3 was applied to the case study organization. Some general recommendations are provided to the company for further utilization of BIM for automated BREEAM-NL assessments. These recommendations are further elaborated for one example credit, along with a working prototype as discussed in Chapter 6.

5. **Validation:** To test the validity of results, two methods are employed. First, the prototype results are validated through a case study project. Following this, a summary of the research results were sent out to BIM & BREEAM experts within the case study organization and semi-structured interviews were conducted to get their opinions. The feedback from the experts and the answer to the final sub-question is discussed in Chapter 7.

Chapter 3

Literature Review

The research problem corresponds to two knowledge fields: BIM and BREEAM-NL. To understand the context of the research problem and the relationship between the two knowledge fields, relevant academic works are reviewed. The results of the literature review is discussed in this chapter in three parts: *Introduction to BIM*, *Introduction to BREEAM-NL* and *BIM for BREEAM-NL*. The knowledge obtained from this chapter will form the theoretical foundation upon which the rest of the research will be built upon. Research questions expected to be answered at the end of this chapter:

SQ 1: Theoretically, how can BIM help in the assessment process of BREEAM-NL?

3.1 Introduction to Building Information Modeling

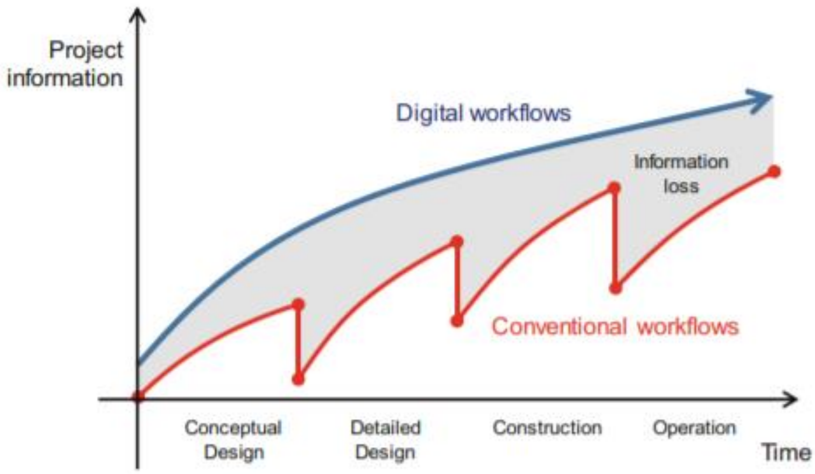


Figure 6 Information losses with conventional workflows in construction projects (Borrmann et al., 2018)

Construction projects are complex in nature due to the involvement of a wide range of stakeholders and the interdependencies between them. Information exchange and collaboration are the key ingredients for the successful realization of buildings and infrastructure. Traditional medium of information exchange was through the handover of technical drawings which was done manually until the introduction of CAD technologies to the AEC industry in the early 1980s provided faster and more efficient opportunities for data sharing, manipulation and integration (Kasim, 2015). But the depth of information that can be conveyed through 2D graphical drawings is very limited and leads to the loss of information at each exchange point (Figure 6). Significant amount of effort goes into extracting the required information to execute the subsequent steps. These inefficiencies in the conventional workflows of AEC industry paved the road to the concept of Building Information Modeling.

Building Information Modeling has become a trending buzzword in the AEC industry in the past decades. The term first appeared in Nederveen and Tolman (1992) but started to be widely recognized in the industry only after the release of Autodesk's first white paper on BIM in 2003 (Autodesk, 2003). While it is being widely adopted in the AEC industry, there is yet no consensus on some of the common terminologies used. The following sections will provide a brief description to the key concepts related to BIM.

3.1.1 The definition of BIM

There is a lot of ambiguity surrounding BIM and its meaning and interpretation has taken many forms over the years. The most commonly used versions, as cited in Bouw Informatie Raad (2015) are:

1. Building Information Models – This version focusses on the representation part; A digital representation of the design and as-built scenario.
2. Building Information Modeling – Here, the focus is shifted towards the process of creating the digital models in close collaboration with other stakeholders using a set of digital tools.
3. Building Information Management – In this version, information is the central aspect of BIM. Using BIM is all about the creation, use and re-use of building information.

The second version encompasses the multidisciplinary nature of BIM and therefore, in the context of this study, BIM stands for **Building Information Modeling**, and is defined as:

"*A set of interacting policies, processes and technologies that generate a methodology to manage the essential building design and project data in a digital format throughout the building's lifecycle*" - Penttila (2006) as cited in Succar et al., (2012)

3.1.2 BIM Uses

A BIM use can be defined as *"A method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives"* (Kreider & Messner, 2013). Based on the purpose of implementation, BIM uses can be primarily classified into five types, as shown in Figure 7. A non-exhaustive list of examples of secondary BIM uses is shown in Appendix A.

Primary BIM Use	GENERATE	GATHER	ANALYSE	COMMUNICATE	REALIZE
Secondary BIM Use	Design, prescribe, arrange etc	Capture, Monitor, Quantify, Classify	Coordinate, Evaluate, Predict, Validate	Visualize, draw, document etc	Fabricate, assemble, regulate etc

Figure 7 Primary and secondary uses of BIM (Adapted from Kreider & Messner, 2013)

1. **Generate:** The purpose of this BIM use is to create information about the building. Examples include prescribing the arrangement of zones or type of walls to be used in the design phase, or specifying the materials or equipment used in the construction phase. Every time a new model is authored or new information is added to the BIM model, information is generated.
2. **Gather:** To collect and organize information about a building at any lifecycle phase. Examples of such BIM uses include capturing the current status of the facility, quantifying the amount of material present in a facility etc. The objective of this BIM use is to merely observe and gather information about the building, but not to make any analysis or inferences from this data.
3. **Analyse:** The purpose of this use is to examine the features of a design or facility to evaluate or predict its performance. In order to implement this BIM use, information has to be first generated and then gathered.
4. **Communicate:** To share the information about the building and the analysis results with other stakeholders involved in the project. This is often a by-product of the other BIM uses. The medium of communication may include 3D realistic visualizations or 2D drawings or other project related documents.

5. **Realize:** The purpose of this last use is to produce a physical element using BIM data. Still in the initial stages of its implementation, this BIM use will give the industry the power to remove human input in the production, assembly and control of facility elements.

   The secondary uses of BIM under each primary use is shown in Figure 7

3.1.3 BIM Fields

BIM fields refer to the domains of BIM activity and the associated players, deliverables and requirements. Succar (2009) identified three interlocking BIM fields namely Technology, Policy and Process. Each field can be distinguished by its requirements, actors involved, and their deliverables as seen in Figure 8.

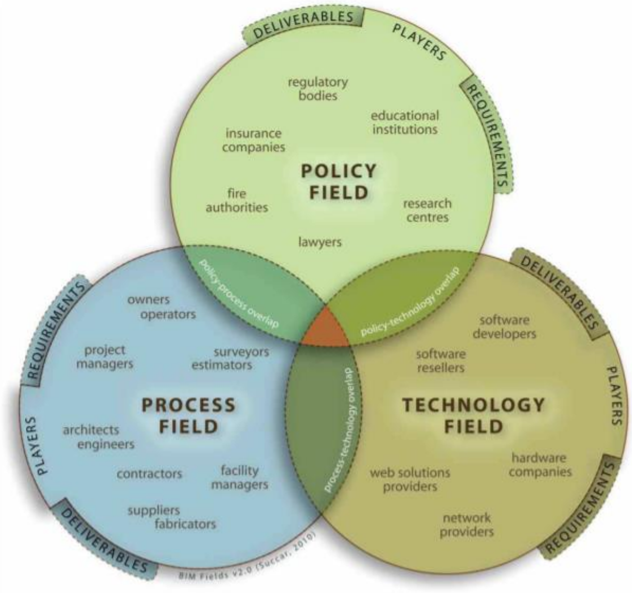


Figure 8 The interlocking fields of BIM activity (Succar, 2012)

The technology field refers to the development and procurement of hardware and software systems, network solutions that support the design, construction and operation of AEC projects. The requirements of this field include improvements in speed, accuracy and efficiency of design and construction activities. The players relevant for this field include technology enthusiasts, software developers and vendors, network providers, hardware companies etc. The deliverables in this field are technical solutions such as 3D modeling tools, automation scripts, user manuals etc.

The process field refers to the organization of work activities between different project stakeholders, associated inputs and outputs. The requirements of this field include information management, BIM training. The players relevant for this field include owners, architects, MEP designers, engineers, contractors etc. The deliverables in this field are 3D models, 2D documentation etc.

The policy field refers to the creation of rules, protocols and guidelines that govern and regulate the design and construction practices in AEC projects. The players relevant for this field include clients, educational institutions and research foundations (such as BuildingSMART), regulatory bodies etc. The deliverables in this field are BIM protocols, contractual agreements etc.

The interactions between these fields occur in the form of either knowledge transfer, data transfer or joint deliverables.

3.1.4 BIM Maturity Stages

The journey from CAD based workflow to a fully integrated BIM process does not happen at once, but rather in incremental stages. This progression in the extent of BIM adoption is defined by BIM maturity stages. The various BIM maturity stages as defined in Succar (2009) are shown in Figure 9.

Figure 9 BIM Maturity stages (Succar, 2009)

1. **Pre-BIM:** The pre-BIM stage, representing the period before the introduction of BIM to the industry is characterized by 2D information exchange. The interest and investment in technology in this stage is very low.
2. **Stage 1- Object based modelling:** The use of BIM is initiated through the adoption of object-based 3D modeling tools such as REVIT or ArchiCAD. At this stage, each discipline generates its own 3D model and the communication between various disciplines is asynchronous and unidirectional.
3. **Stage 2- Model based collaboration:** At this stage, stakeholders in various disciplines will have gained 3D modeling expertise in their domain. Model based communication starts to replace the traditional 2D document-based system. Project teams start drafting BIM agreements/ protocols at the beginning of a project.
4. **Stage 3- Network-based integration:** In this stage, information rich BIM models from all disciplines are shared and managed through a network based Common Data Environment (CDE). All the project activities from various disciplines are integrated and concurrently planned to optimize design and constructability.
5. **Stage 5- Integrated Project Delivery:** According to Succar (2009), this is a representation of the long-term BIM vision. It is characterized by improved collaboration, integrated workflows across all disciplines and a high degree of automated processes. This stage is defined in generic terms to make place for future technological BIM developments.

These BIM Maturity stages can be further elaborated across the three BIM fields of Technology, Policy and Process. This description is provided in Table 1.

Table 1 BIM Maturity stages (Adapted from Succar (2009))

BIM stages / BIM Fields	Pre-BIM	Stage 1: Object based modeling	Stage 2: Model based collaboration	Stage 3: network-based integration	IPD
Technology	2D CAD drawings used to represent 3D geometry. Investment in technology	Parametric tools used to create discipline specific 3D models.	Use of BIM authoring tools goes beyond visualization of geometry. Additional features such as scheduling, estimation	Characterized by the use of project specific network solutions; Modeling requirements established to allow for	Optimization of data, software use and modeling processes through continuous testing and evaluation.

	is low to absent.			interdisciplinary performance analysis at early stages	Maximizing project performance through 'nD'models
Process	Linear workflows; collaboration between disciplines is not a priority.	Data exchanges are primarily 2D exports made out of 3D models. No significant improvement in collaboration	Collaboration becomes a high priority. BIM implementation strategies and detailed action plans are communicated to the whole team; BIM roles are now visible	Bi-directional, synchronous collaboration around unified central data models. BIM roles are reflected and embedded within organizations.	All the design phases are fully integrated and occur in parallel to each other. Active monitoring and revision of BIM implementation strategies by all stakeholders.
Policy	No policies in place to ensure collaboration or specific format of information delivery	Basic BIM modeling and documentation standards are specified.	Detailed BIM guidelines for modeling standards, LOD, object specifications etc. Contractual agreements on BIM intellectual property rights, conflict resolution system are made.	Risk-allocation, reward mechanisms and procedural flows are well established in the contractual agreements.	BIM protocols and associated contractual agreements are continuously revisited and revised.

3.1.5 Green BIM

The convergence of green buildings and BIM is termed as 'Green BIM.' It is an emerging form of project delivery and design that is centred around leveraging the uses of BIM to design, optimize and deliver sustainable built assets. Krygiel and Nies (2008) was 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 has to offer for green building projects.

Lu et al., (2017) illustrated the nexus between BIM and Green buildings in a "Green BIM Triangle" taxonomy (Refer Fig 10). They identified three primary facets of the integration of BIM in green building delivery: 1) BIM supported lifecycle functions 2) BIM supported environmental analyses and 3) BIM supported green building assessments. The scope of literature review for this research is limited to the third facet i.e., BIM supported green building assessments. The following sections will discuss the literature findings on this topic.

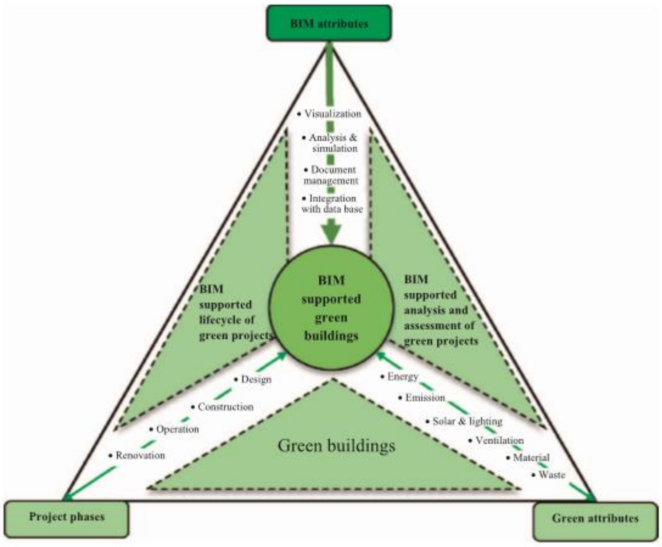


Figure 10 Green BIM Triangle taxonomy (Lu et al., 2017)

3.1.5 Green Building Assessments (GBA)

Green Building Assessments refer to the process of evaluating the performance of a design or a facility against a set of predefined sustainability criteria laid out in green codes or certification systems. Some of the common GBA frameworks include rating systems such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Green Building Index (GBI) etc.

Each of these rating systems cover a wide range of sustainability related topics divided into small parts known as 'credits.' To gain a particular credit point, it has to be demonstrated that all the requirements of the credit have been fulfilled by a design along with a submission of supporting evidence. The requirements relate to various aspects of building performance such as energy efficiency, carbon emissions, material consumption and circularity, waste reduction etc.

3.1.6 BIM for Green Building Assessments

Green Building Assessment process is often laborious and time consuming. Its complexity arises from the fact that large volumes of interdisciplinary information is required to demonstrate compliance with the certification requirements and this data is distributed between different project stakeholders. Therefore, information management is quite challenging. In addition, AEC projects undergo several design changes in the preconstruction phase and with each change, the assessments have to be repeated. This is where the use of Building Information Modeling (BIM) comes into picture. One of the unique selling points of BIM lies in the promise of intelligent data integration in an otherwise fragmented industry.

Research on methods to facilitate green building assessments using BIM has been receiving increasing attention lately for three practical reasons: 1) This integration can help designers in choosing effective strategies for achieving sustainability ambitions in the early design stages, 2) It can aid the sustainability experts in assessing the design compliance with green building certification requirements in a faster, more efficient manner and 3) It can also facilitate and streamline the massive document management required for achieving these certifications (Lu et al., 2017). The previous works on this subject can be grouped into two groups: BIM-based GBA tools and BIM-based GBA processes. The following sections will present the literature results in each of these groups.

3.1.7 BIM-based GBA tools

Early works on BIM integrated GBA tools focused on relating sustainability indicators to REVIT project parameters (Barnes & Castro-Lacouture, 2009; Nguyen et al., 2010; Azhar et al., 2011; Wong & Kuan, 2014). Azhar et al., (2011) proposed a conceptual framework for the integration of BIM in the LEED certification process by mapping the various sustainability analyses that can be performed by multiple BIM tools to the LEED credits that can be obtained using them. To this day, this remains as one of the most popular pioneering works on this topic.

Since then, the research evolved further in terms of the number and type of credits linked to BIM, integration with different external databases and exploration of various types of automation tools. Automated assessment modules were created using platforms such as REVIT API (Chen & Nguyen, 2017; Jalaei & Jrade, 2015), Microsoft Excel Macros (Akcay & Arditi, 2017), Dynamo for REVIT (Bergonzoni et al., 2016). However, most of these studies focused on specific parts of various green certifications. Software tools that can fully automate all the assessments for a given green certification system based out of BIM models are not yet available. Autodesk REVIT in BIM authoring tools & IES-VE in BIM-based performance analysis tools are the most commonly used software for automation (Ansah et al., 2019 & Carvalho et al., 2020).

Currently it is estimated that it is possible to link about 67% of LEED credits and 24% of BREEAM credits to BIM, and in both cases, Energy and Material related credits show the highest potential for integration (Carvalho, 2020). Using these past studies as reference, further details on how to approach the integration of BIM for BREEAM-NL credits will be discussed in Section 3.3, after providing an introduction to BREEAM-NL in Section 3.2.

3.1.8 BIM-based GBA process

While technology enables the automation of the green building assessments, implementation in practice would require changes in the current processes and associated roles. Wu & Issa (2013) provided an overview of the existing Green BIM practices and proposed an Integrated Green BIM Process Map (IGBPM), providing a roadmap for including Green BIM practices in the early design phase. Using a couple of credits from LEED as a use case, they developed a further detailed step-by-step operational guide to demonstrate the execution of specific Green BIM practices.

Zanni et al., (2014 & 2016) adopted a practice-oriented approach to present a management viewpoint to BIM-enabled sustainability framework. Through in-depth interviews of industry practitioners, they identified the typical sustainability tasks and aligned them to BIM requirements. These studies however, do not discuss the assessments and documentation processes for green certifications.

3.1.9 Challenges and barriers to BIM based GBA

Significant progress has been made in the academic research with regards to unveiling the potential uses of BIM for green building assessments and ways to integrate it. However, there are still quite a few challenges facing its implementation in practice. On the technological front, interoperability between BIM tools, the lack of replicability and scalability in the previously demonstrated scholarly works are some of the barriers to further utilization of BIM for GBA (Ansah et al., 2019).

In their comprehensive review on the applicability of Green-BIM and directions for future research, Lu et al., (2017) concluded that apart from the technological hurdles, industry is also lacking clear standards for effective implementation of green BIM applications. The number of scientific works that focused on the execution aspects of BIM based GBA are far too less in comparison to the ones centred around technology. Switch to a BIM based assessment process also results in a change in the current roles and responsibilities of the stakeholders involved. Changes in contractual and BIM protocol documents must be made to accommodate these changes in roles. These policy related aspects for an effective integration of BIM and GBA are not sufficiently researched upon. Alsehrawy et al., (2020) pointed out that apart from BIM and GBA related challenges, other factors such as lack of awareness among practitioners, resistance to change and budget constraints in projects could also hinder the implementation in practice.

Lu et al., (2017) concluded that the current research related to the possibilities, advantages and challenges of BIM-GBA integration is from a theoretical standpoint. Further research must investigate the needs of the industry practitioners with regards to green BIM uses. This discussion is currently lacking industry perspective, as none of the previous research works examined the current level of BIM use for green building assessments.

3.2 Introduction to BREEAM-NL

Building Research Establishment Environmental Assessment Method (BREEAM) was first introduced in 1991 by the centre for sustainable construction – a sub-division of the Building Research Establishment (BRE Global). In the following decade, several national and regional adaptations of this certification scheme were developed. BREEAM-NL is one such national adaptation of the international scheme tailored to the regional context of the Netherlands. The following sections will elaborate on the relevance of the certification scheme in the Dutch construction industry, how it relates to the international scheme and finally, the topics covered in the assessment guideline.

3.2.1 Relevance in the Dutch construction industry

In 2009, the Dutch Green Building Council chose BREEAM as their sustainability label and released a national adaptation of the certification scheme known as BREEAM-NL. This national adaptation has been tailored to fully integrate the national building regulations such as Energy Performance Coefficient (EPC) calculations within the certification scheme. Since then this assessment guideline served as a measuring instrument for assessing the extent of sustainability in construction projects in the Netherlands.

Currently it has four hall marks depending on the type of project: New Construction & Renovation, In-Use, Area development, and demolition and disassembly. Each hallmark has a different assessment guideline that is revised periodically. Each of these hallmarks is further divided into different sustainability related topics.

3.2.2 Comparison with BREEAM International

For the most part, the contents of the BREEAM-NL assessment guideline aligns with that of the international scheme. The same sustainability topics (Categories) and quality marks are covered in both the guidelines. The requirements, however, are tailored to suit the Dutch norms and legal standards.

An important distinction has been made in the roles involved in the accreditation process. While BREEAM international only has a licensed assessor that is responsible for assessing the documentation submitted by the design team, DGBC recognizes and trains 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. The expert is responsible for doing the preparatory work of providing advice and consultancy, gathering the required documentation and uploading it to the assessment tool.

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 decision on certification.

This difference in roles is also observed in comparison with other certification schemes such as LEED where the design teams submit the evidence directly to the U.S. Green Building Council. This role distinction plays a crucial role in the implementation of BIM for automated compliance verification as the tasks of data creation and data analysis are distributed between different stakeholders. Chapter 4 will further discuss the roles and responsibilities of all the stakeholders involved in the BREEAM-NL assessment process.

3.2.3 Topics covered in BREEAM-NL

BREEAM-NL assessment guidelines are divided into nine '*Categories*' based on the topic they deal with. Figure 11 shows the different categories and their weightage in the New Construction & Renovation Hallmark of BREEAM-NL. Energy category has the highest weightage at 19% followed by Health & Comfort at 15% and Materials at 12%. The building elements that fall under the scope of BREEAM-NL credits include the building plot, structural components, installations as well as finishing components.

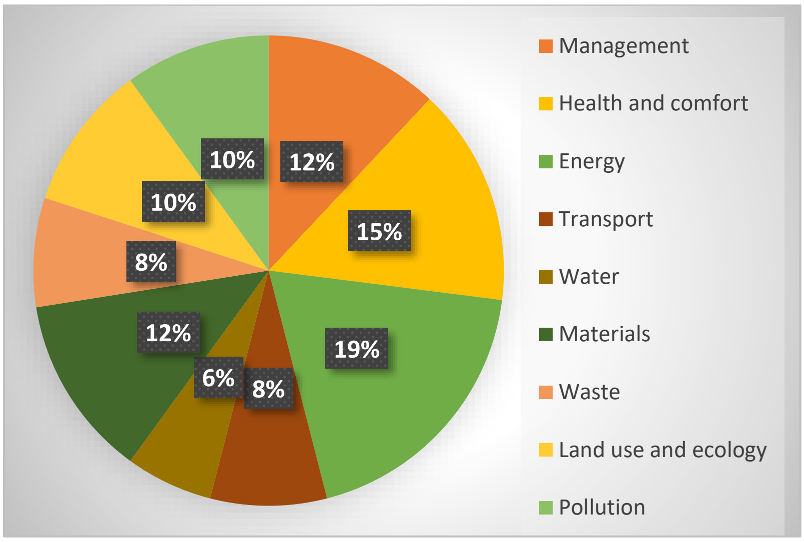


Figure 11 BREEAM-NL New Construction & Renovation – Composition

Each of these categories is further divided into smaller subjects known as 'credits'. Sustainability objectives and conditions of fulfilment are defined for each credit in the assessment guideline. While some credits are mandatory, most of them have a freedom of choice. Therefore, based on the client's ambitions and the project constraints, project teams can decide which of the credits they want to pursue in order to build up a total score to achieve the desired certification level. There is also a possibility of receiving innovation credits for exemplary performance, that is above and over the requirements stated in BREEAM-NL.

Due to the time limitation associated with this project, not all the categories could be studied in detail. Studies reviewing the state-of-the-art on the topic of BIM based GBA revealed that credits related to energy and materials have the highest potential for integration with BIM, followed by indoor environment related credits. This is because the data needed to verify compliance for these credits can be easily obtained from BIM models or BEM models. Whereas this is not the case for credits relating to other categories such as management or pollution, for example. For this reason, the scope of this thesis project is limited to Energy and Material categories.

A brief description of the objectives of each of the credits in these two categories, criterial for fulfilment, input data required for assessment and documentation evidence will be discussed in the following sections. It must be noted that the list of credits and their requirements may change in every revision of BREEAM-NL guideline. Currently, BREEAM-NL 2020 is the latest version of the assessment guideline. However, for this thesis, BREEAM-NL 2014 v2 has been used as the reference because the client company has not yet worked with the new version and therefore, could not provide accurate information about its assessment process.

3.2.4 Energy

At the highest weightage of 19%, the aim of the energy category is to assess measures for improving the energy efficiency of the building design and also encourage the use of energy efficient services and equipment. This category is comprised of 9 credits with a maximum achievable total of 29 points and 3 innovation credits.

A brief description of the contents of these credit points and their assessment methods is provided below in Table 2. A more detailed elaboration of the input data required for assessments and the output evidence needed for documentation is provided in Appendix B.

Table 2 Overview of the credits in 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 CO2 emissions due to building related energy consumption	Percentage improvement in Energy Performance Coefficient (EPC) as compared to the Energy Performance Standard (EPN) has to be calculated
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 CO2 emissions.	Specific lighting power per lux calculation and verifying if it’s under 0.1 W-Lux/ m2. Input parameters:

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: Minimising air filtration	1	To promote CO2 reduction through efficient design that minimized heat and cold losses.	Qualitative design verification to ensure the application of appropriate interventions for minimal loss of heat & cold
ENE 07: Energy efficient refrigeration and cold storage	1	To promote energy savings and CO2 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 CO2 reduction through the use of efficient elevators	Verifying that the specifications of the elevators meet the requirements
ENE 09: Energy efficient escalators	2	To promote energy savings and CO2 reduction through the use of 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	29		

3.2.5 Materials

The aim of this category is to encourage conscious selection of construction materials in order to minimise their impact on the environment throughout their lifecycle starting from extraction of raw materials to recycling. The category is comprised of four credits with a maximum achievable score of 17 points and a possibility of earning two innovation points for exemplary performance. An overview of the contents of these credit points and their assessment methods is provided below in Table 3. A more detailed elaboration of the input data required for assessments and the output evidence needed for documentation is provided in Appendix B.

Table 3 Overview of the credits in Energy Category, BREEAM-NL 2014 v2 (Derived from the BREEAM-NL guideline)

Credit description	Max score	Sustainability objective	Assessment method
MAT01 Environmental performance	8	To encourage the use of materials with low environmental impact.	MPG Calculation using material quantities and associated NMD database for environmental impact

MAT05 Substantiated origin of materials	4	To encourage the use of materials with a responsible origin in the main building parts.	Based on the type of procurement of materials and their associated volumes, a final score is obtained using MAT05 excel tool provided by DGBC
MAT07 Robust design	1	To promote protective design measures in exposed building parts in order to minimize the frequency of their replacement.	Design verification of appropriate protection measures in zones deemed to have high damage risk
MAT08 Building flexibility	4	To encourage design with higher degrees of flexibility and adaptability.	Based on the inputs regarding the design and location of structural and utility elements, a score is obtained using the building flexibility calculation excel tool provided by DGBC
Total credit points	17		

3.3 BIM for BREEAM-NL

Building upon the theoretical foundation provided in the previous sections to the concept of BIM & BREEAM-NL rating system, this section aims to establish the relationship that exists between the both, and how the latter can benefit from the use of BIM. The following sections will discuss the applicable BIM uses for BREEAM-NL credits and how the assessment process can be automated based on the literature findings.

3.3.1 BIM uses for BREEAM-NL

Of all the BIM uses discussed in Section 3.1.2, the ones relevant for the BREEAM-NL assessment process is shown in Figure 12. For architectural and MEP designers, the important BIM uses relate to generating information through authoring 3D models and communicating the same to other project stakeholders via documentation and visualizations. For the BREEAM-NL expert team, the relevant uses primarily relate to gathering necessary information from BIM Models and using that for performance analyses and code validation. The exact relationship between BIM uses and each of the BREEAM-NL credits depends upon the nature of the input requirements.

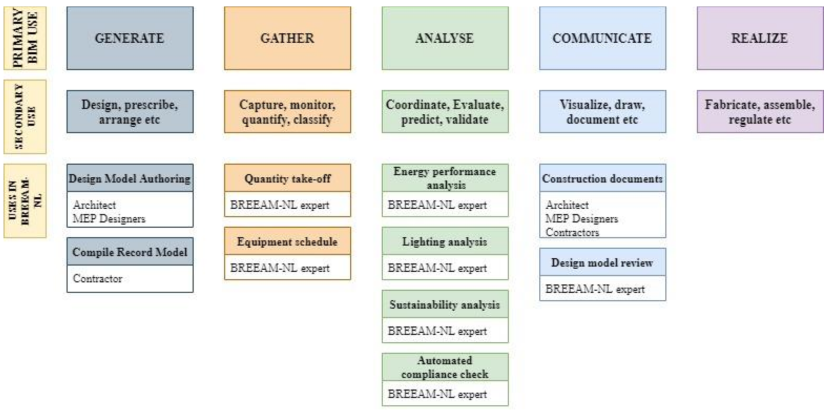


Figure 12 BIM Uses for BREEAM-NL (Own analysis)

3.3.2 Classification of BREEAM-NL credits

On a broad scale, one can classify BREEAM-NL or any other green certification system's credits into two types: 1) Qualitative and 2) Quantitative. Qualitative credits are the ones that require human judgement to assess the degree of compliance. An example of one such credit could be ENE06. This credit requires demonstration of 'appropriate design measures' to minimize heat/ cold loss. The appropriateness of the design interventions cannot be objectively measured or quantified. Therefore, it would not be possible to automate the assessment of such credits.

Quantitative credits on the other hand, can be measured. There is a defined output or performance level expected to gain the associated credit points, and the input parameters that will be used to measure this performance can be obtained from BIM/ Building Energy Models (BEM). Therefore, there is a possibility of automation in this scenario based on the availability of required technical infrastructure.

However, in order to design a practical strategy to integrate BIM in the BREEAM-NL assessment process, further examination and classification of these quantitative credits is needed. Because, the inputs required for the calculation of these credit points is not always coming from BIM models alone. For this reason, this thesis project proposes the following classification of credits for BIM-BREEAM mapping based on their input data type:

1) Type 1: Credits for which all the input parameters can be obtained from BIM models and therefore, assessment process can be fully automated.
2) Type 2: Credits for which the input parameters are obtained from BEM models and the assessment process can only be partially automated because the transfer of BIM models requires some level of human intervention.
3) Type 3: Credits for which the input parameters are obtained from BIM models PLUS an external database (*such as National Material Database (NMD) for the assessment of MAT01*). The automation process can be fully automated for this type of credits.
4) Type 4: Credits that cannot be directly linked to BIM either because compliance with the requirements can only be demonstrated with human input or using information outside BIM models such as contractual documents.

Based on this classification, Table 5 provides an overview how many of Energy and Material credits fall into each of the defined types. This is done through a qualitative analysis of the requirements of ENE & MAT credits and by looking into previous academic work for a proof of concept for their association with BIM.

3.3.3 BIM uses vs BREEAM-NL credit types

For each type of credit discussed in the last section, the applicable BIM uses vary. For type 1 and 3 credits, intelligent data gathering through take-offs and schedules, environmental impact analysis and fully automated code validation are the applicable BIM uses. For Type 2 credits performance analyses for lighting, thermal comfort, energy efficiency and partially automated code compliance are the applicable BIM uses.

Through a qualitative analysis of the requirements of each of the energy and material category credits, the number of credits falling into each of the defined types is obtained. This also gives an idea of how much percentage of the credit points can be automatically assessed using BIM. The results of this analysis is shown in Table 4.

Table 4 BREEAM-NL credit types vs BIM uses (Own analysis)

Type of credit	Input source	BIM Use	List of credits	% of credit points	Possible level of automation
TYPE 1	BIM Model	Quantity take-off, equipment schedules	ENE02, ENE04, ENE07, ENE08, ENE09, MAT05, MAT08	35	Full
TYPE 2	BEM Model	Energy performance analysis, Lighting analysis	ENE01, ENE05	39	Partial
TYPE 3	BIM Model + External database	Quantity take-off; Environmental impact analysis	MAT01	17	Full
TYPE 4	Assessment cannot be automated by BIM	Construction documents & Design model reviews	ENE06, ENE26, MAT07	9	None

3.3.4 Approaches to BIM-BREEAM-NL Integration

There are two primary components in a BIM-GBA integration framework: Input module and assessment module. Input module refers to the format of the source information required to perform calculations to verify compliance. Assessment module refers to the software architecture required to make performance assessments and compare it with GBA requirements.

Several authors explored the technical possibility of using BIM for green building assessments and this wealth of information can be used to make an inventory of possible approaches for BIM-BREEAM integration. The results from the literature are divided into three categories based on the type of credits and the integration approaches are summarized below. An elaborate inventory of the previous works, the tools and approaches adopted as well as the credits used for verification is provided in Appendix C.

Type 1: For these credits all the input information required for verifying the compliance and calculating the final score can be stored in BIM models. REVIT is the most commonly used BIM authoring tool for this type. The assessment tools developed include simple Excel/ other database functions or REVIT based solutions such as Dynamo scripts of custom-made plug-ins. Zhang et al., (2019) developed a cloud-based application using Autodesk Forge that uses IFC file format as the input for assessments. The results are summarized in Figure 13.

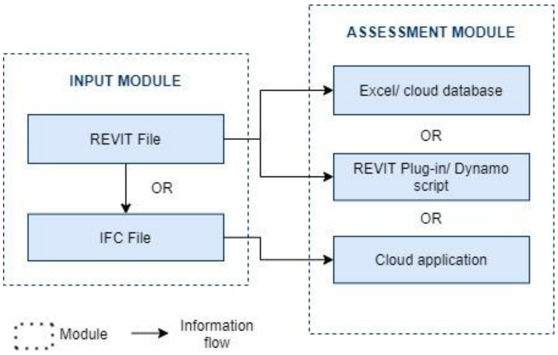


Figure 13 BIM Integration approaches for Type 1 credits (Analysis based on literature)

Type 2: These credits require energy modeling results as input parameters to assess the level of compliance with the requirements. Therefore the input module includes an additional component for energy modeling, either a REVIT based plug-in or a different software program for energy modeling which requires BIM data imported in file formats such as gbXML. The assessment modules used were either cloud-based applications using Jess rule engine or REVIT-based plug-ins. The results are summarized in Figure 14.

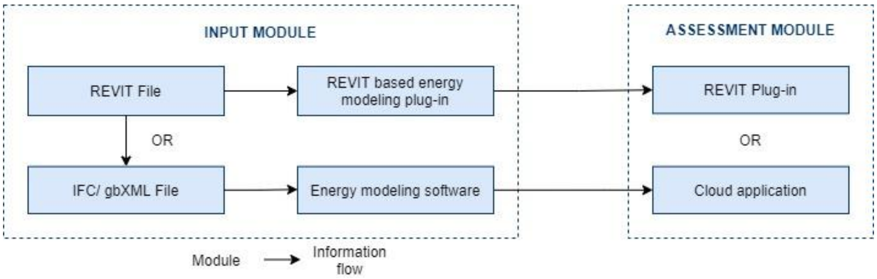


Figure 14 BIM Integration approaches for Type 2 credits (Analysis based on literature)

Type 3: Similar to Type 1, data from BIM authoring tools is retrieved for the assessments along with an external database such as the National Material Database (NMD). The solutions proposed for assessment module include REVIT-based tools such as Dynamo script/ plug-in, desktop or cloud-based applications as shown in Figure 15.

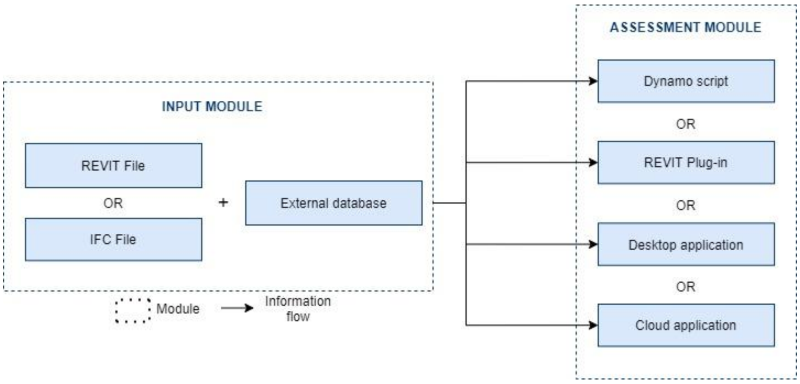


Figure 15 BIM Integration approaches for Type 3 credits (Analysis based on literature)

It must be noted that these are not the only possible solution approaches, but rather frameworks adopted and tested in the previous works.

3.4 Summary

This chapter provided an introduction to the concepts of BIM and BREEAM-NL assessment scheme. In the first part of the Chapter i.e., 3.1, key terminology related to BIM were first discussed, followed by a review of the state of the art related to the use of BIM for Green Building Assessments. 3.2 provides a brief introduction to the BREEAM-NL assessment scheme, the sustainability topics covered in the guideline and a more detailed analysis of two of these topics: Energy and Materials. The last part of the Chapter, 3.3, discusses the synergy between BIM and BREEAM-NL. What BIM uses are relevant for the assessment process, how many of the credits in Material and Energy categories can be automated using BIM and what are the different approaches to the integration.

Some preliminary conclusions can be drawn based on this literature study. First, there are some technological limitations to the extent to which the GBA process can be automated using BIM. These limitations arise from interoperability issues for information exchanges between the different BIM tools used in practice. Green building certifications cover a wide range of sustainability topics and no single BIM tool can currently support all the assessments. Therefore, data exchange is a critical challenge for automation. Second, from an implementation perspective there are still some challenges facing the integration of BIM and GBA. In the last ten years, several researchers studied the possibility of the automation of green certification credits through BIM. However, these studies do not discuss what changes must be made by the design teams in their current working methods to implement these tools in practice. The boundary conditions that limit the application of automated assessments in practice, such as BIM maturity, effort to benefit ratios are also not discussed in literature. Third, the knowledge currently available on this topic does not reflect the actual status of implementation of BIM for GBA or the needs of the industry. Since the goal of this thesis project is to aid practitioners in the implementation of BIM for BREEAM-NL assessments, the second and third issues will be addressed in this report.

To address the first research question,

SQ 1: Theoretically, how can BIM help in the assessment process of BREEAM-NL?

BIM can assist the BREEAM-NL expert team in streamlining the assessment process through intelligent data acquisition, performance analysis and automation of assessments. What BIM uses are applicable and to what extent the assessment can be automated varies with the type of credit in question. In Energy and Material categories of BREEAM-NL, that is worth a maximum of 46 points in total, the calculation of 9% of the credit points cannot be achieved using BIM. For the rest, integrating BIM within the BREEAM-NL assessment process will result in partial or full automation of the calculation of credit points. The literature summary on the frameworks for BIM-GBA Integration can be used as an inventory of potential solution approaches.

Chapter 4

Insights from Practice

To investigate to what extent the relevant BIM uses mentioned in Chapter 3 are being used in practice in the BREEAM-NL assessment process, semi-structured interviews with industry experts were conducted. BREEAM-NL project managers, material and energy experts, architectural and MEP designers involved in the certification projects were first interviewed. To gain insights about the level of BIM awareness in the organization and implementation challenges, 2 BIM experts were interviewed. 1 external automation expert was also consulted to gain insights into the process of developing automated solutions for the needs of the AEC industry and the critical factors for successful adoption. This chapter will present the findings from these interviews. Research questions expected to be answered at the end of this section:

SQ 2: To what extent BIM is currently being used in BREEAM-NL assessment process?
SQ 3: How does the industry situation compare to the promised potential of BIM for green building assessments? What are the reasons for the gap?

4.1 Relevant stakeholders

The key stakeholders involved in the BREEAM-NL assessment process, and how they relate to each other is shown in Figure 16. The process starts with the client's ambition which is then translated into a program of requirements by their representatives. This document guides the design process for Architects & 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. There is a bi-directional association between the design teams, contractors and certification team that will result in the optimization of the design. And lastly, the BREEAM-NL team submits the documentation to an assessor that will ultimately be responsible for the assessment report which forms the basis for the final decision on BREEAM rating by DGBC.

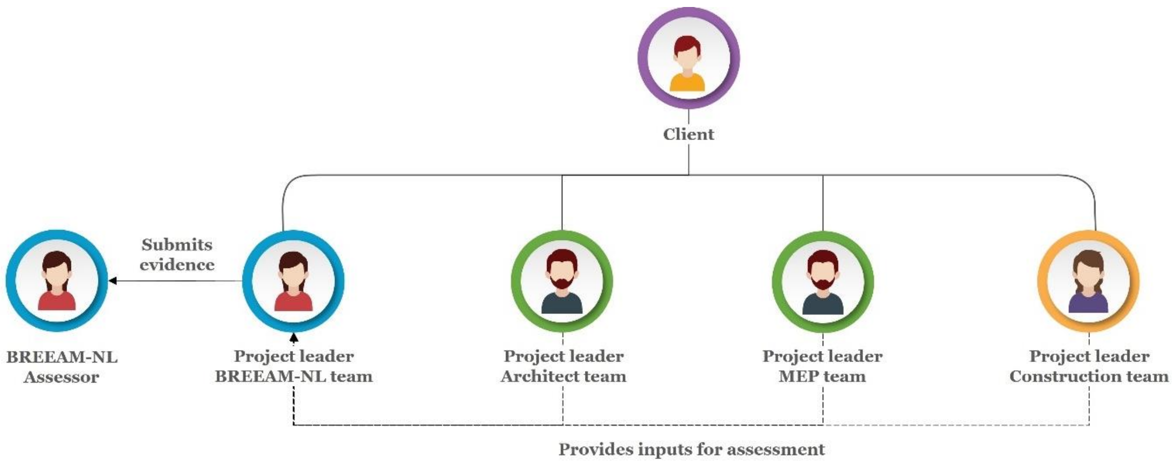


Figure 16 BREEAM-NL stakeholder organizational structure

Using this organizational structure as a reference, the following actors have been interviewed to gain some insights about the current workflow. The aim of the interviews with the BREEAM-NL project managers (B1,B2,B3) was to identify the common challenges faced in the BREEAM-NL assessment process. The rest of the interviews were conducted with a aim to understand the assessment process for specific credits. Details of the interviewees and summary of the questions and their responses is included in Appendices D & E. Actors involved in the construction phase of the projects could not be interviewed due to time constraints. This is one of the limitations of this study.

Roles & responsibilities of key stakeholders in the BREEAM-NL assessment process

1. **Client:** The main role of the client in the BREEAM-NL certification process is to state the level of ambition and include the same in the program of requirements handed out to all project teams. The responsibility of appointing and empowering a BREEAM-NL expert to lead the certification process also lies with the client.

2. **BREEAM-NL Expert:** The primary role of a BREEAM-NL expert is to advise the client on how to achieve the set sustainability ambitions through BREEAM-NL. Starting from performing a quick scan to identify the target BREEAM-NL credits, the expert will provide guidance and support throughout the design and construction phases.

   BREAAM-NL responsibilities:
   1. Perform a quick scan at the beginning of a project and provide a strategy for achieving the desired ratings
   2. Communicate the BREEAM-NL strategy with the other stakeholders and specify their responsibilities
   3. Perform compliance verification at the end of every construction phase and provide feedback to the design teams and/ or contractors
   4. Gather required evidence at the end of the design phase and submit documentation to the BREEAM-NL assessor for interim certificate
   5. Draft a contractor agreement document describing the responsibilities of the contractors and the protocol they have to abide by.
   6. Monitor the construction progress and review if the as-built scenario is BREEAM-NL compliant. Facilitate documentation for the final assessment.

3. **Architectural & MEP designers:** In the context of BREEAM-NL certifications, the role of architect and MEP team is to understand the requirements from their end and ensure that their designs comply with these requirements to achieve BREEAM-NL rating.

   BREAAM-NL responsibilities:
   1. Ensure that the designs satisfy BREEAM-NL's program of requirements
   2. Provide the Expert team with the required information to perform assessments
   3. Use the feedback received from the expert team after compliance verification to accommodate any required changes
   4. Update the BIM models regularly and keep the expert team always informed of any design changes

4. **Contractor:** After the end of design phase, the BREEAM-NL Expert team drafts a document outlining the requirements and procedures that the contractors must comply with. From this moment on, it is the responsibility of the contractor/ construction manager to ensure that the as-built design does not deviate from the design documents provided and therefore, is BREEAM-NL compliant. In case of any required changes, the contractor has to ensure that they are approved by the client and the BREEAM-NL expert team before execution.

   BREAAM-NL responsibilities:
   1. Comply with the design documents provided at the beginning of the construction phase

2. Update the as-built information in the BIM models shared with the rest of the project team
3. Share the proposals for changes in design with the client and BREEAM-NL expert before execution
4. Provide the documentation required for the post-construction review to obtain the final BREEAM-NL rating

5. **BREEAM-NL Assessor:** BREEAM Assessor is a licensed expert authorized by DGBC to assess the performance of a project based on the evidence submitted by the BREEAM expert. The assessment report provided by the BREEAM-NL assessor is the document upon which the final decision on project rating is determined by DGBC.

   BREEAM-NL Responsibilities:
   1. Impartially review the evidence documents and communicate areas of compliance & non-compliance with the project team
   2. Ensure the robustness and reliability of the certification outcome

4.2 Assessment process

The typical steps involved in the process of acquiring a BREEAM certification for a new construction project is described below from the perspective of BREEAM Consultants. The process described below is a typical representation of the BREEAM assessment process in the Netherlands. Figure 17 illustrates the key activities and decision points.

1. **Quick Scan/ Feasibility Study**: The BREEAM process usually begins after the preliminary design phase. The first activity is to conduct a feasibility study based on the concept design and client's sustainability ambitions. The feasibility study indicates what credits are to be aimed at to achieve the desired BREEAM rating. This information is documented in an Excel scorecard and communicated to the client.

2. **Kick-off Meeting 1**: After obtaining the client's approval for the BREEAM target plan, a kick-off meeting is arranged with the architectural and MEP design managers, where the BREEAM consultants share the target plan with them and give them an overview of what needs to be done. This meeting is presided by the client/ their representative. The project enters the definitive design phase after this.

3. **Verify Design Compliance**: As the design process progresses from developed to technical design stage, it is the BREEAM consultant's responsibility to verify the compliance of the design with the requirements set by BRE to achieve BREEAM certification. This is an iterative process as the design undergoes several changes along the way. The design documents are shared via BIM 360 and updated weekly. The BREEAM consultants are notified of the changes that may impact the rating.

4. **Design stage assessment (Interim Rating)** : This is an optional step in the process of obtaining BREEAM certification, but it is usually carried out as it can be too risky to leave the assessment to the end of construction.

During the definitive design stage, the BREEAM consultant team (or the client, depending upon the contract) appoints a BREEAM assessor. The BREEAM consultant team discusses the list and format of evidence to be submitted in consultation with the assessor. Once the technical design is ready and the design compliance has been checked, the evidence is collected and shared with the BREEAM assessor, who awards an interim BREEAM rating to the project in case of compliance. In the case of non-compliance/ missing evidence, the same is communicated to the project team and the evidence is re-submitted.

5. **Kick-off Meeting 2**: After obtaining the interim rating, the project progresses to construction phase. A kick-off meeting is organized with the construction manager and client representative to communicate the deliverables. The responsibility of complying with the design agreed upon and fulfilling the BREEAM requirements lies with the contractors/ construction managers. The role of the BREEAM consultant team from this point onward is merely facilitating the acquisition of certification by verifying the documents, compiling them and submitting it to the assessor.

6. **Evidence Submission**: As the project nears the end of the completion phase, the BREEAM consultant team gathers the as-built information for evidence submission in the post construction review. The deliverables from the contractors are clearly agreed upon beforehand, and therefore the responsibility of the team is only to do quality checks and submit the compiled information to the assessor. This marks the end of the project.

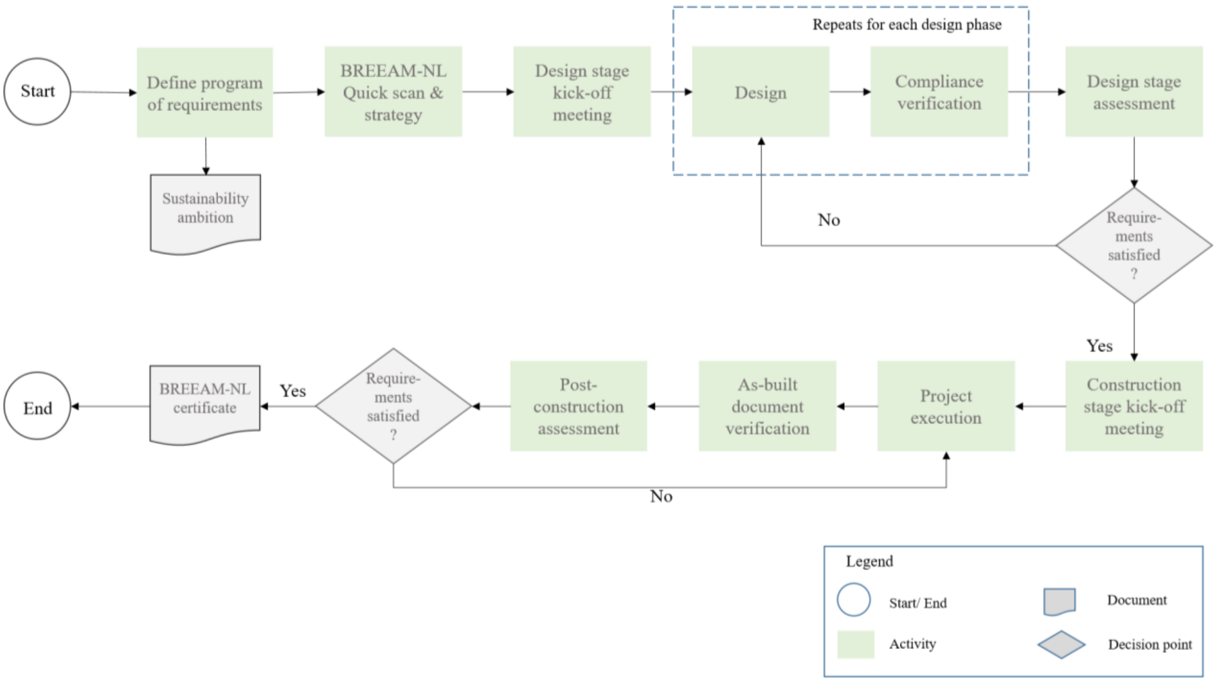


Figure 17 BREEAM-NL certification process

A detailed process map modeled according to Business Process Model and Notation (BPMN) standards is provided in Appendix F.

4.3 Challenges in the current process

General challenges in the current BREEAM certification process as identified from the interviews are as follows:

1. **Roles & responsibilities**: Responsibilities, especially for ensuring the design compliance with BREEAM-NL requirements and the associated information deliverables are not well defined at the project initiation. For the design teams, BREEAM requirements are not always the key priority, especially when the ambition is not set out in the early design phases. Therefore, the information provided to the BREEAM team is often unfiltered and lacking key evidence. This leads to a back-and-forth process of collecting the required information and verifying design compliance (B1 & B2).

2. **Information management:** In order to assess the extent to which BREEAM-NL requirements have been fulfilled, the expert team needs large amount information about the design and construction details that comes from several different stakeholders. Acquiring this information often takes longer than the assessment itself (Interviewee B5). Standardising the data collection process can significantly save time for the BREEAM team.

3. **Change management**: The design undergoes multiple changes in between the design phases which leads to re-assessment of the credit compliance. While not all changes may affect the credit compliance, it is important that the BREEAM experts are notified of these changes on time, so they can assess the nature of its impact before it's too late. In practice, however, this does not happen (B2)

4. **Manual compliance verification:** The design compliance verification is a laborious and time-consuming process, which is currently fully manual. Through biweekly meetings with the design teams, the BREEAM consultant team goes through each of the credits to check if any changes have been made and if yes, do they still comply with the BREEAM requirements (B1 & B2). As discussed in Section 3.3, using BIM, this assessment process can be fully or partially automated for about 91% of the credit points in ENE and MAT categories.

Figure 18 shows how these challenges in the BREEAM-NL assessment process align with advantages of a BIM-integrated workflow.

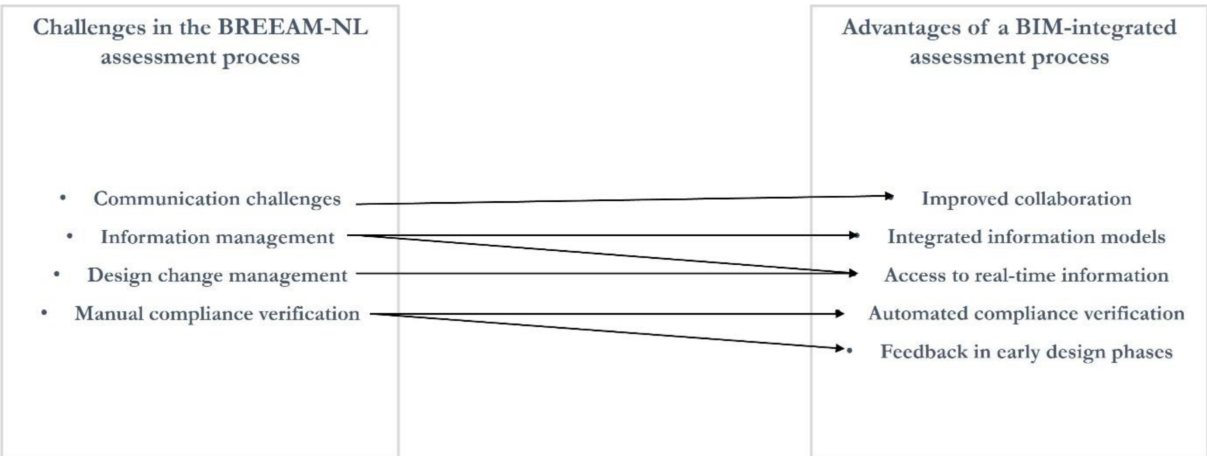


Figure 18 Challenges in BREEAM-NL process vs BIM advantages

4.4 Level of BIM use: Literature vs Practice

From the interview results, the current method of assessment for each of the Energy and Material credits, along with the associated time and number of revisions is documented in Appendix B. The results are summarized below:

1. Currently, BIM is not being used for automated assessments at all.
2. For Type 1 credits in the Energy category, information is primarily shared through 2D drawings because the level of detail for MEP BIM models is not as high as the architecture models. Where as in the Material category, input information for type 1 credits (i.e., MAT05 & MAT08) comes from the BIM models, although it is not always complete. Therefore, the project team requests for additional information usually in an Excel format (Interviewee B4 & B5)

3. For Type 2 credits, the BIM models are not structured well enough to import them into the energy performance assessment tools. Therefore, the energy model is built from scratch using the source BIM model as reference (Interviewee B1 & B6).
4. For Type 3 credits, i.e., MAT01, IFC file is used as the reference to input data into an assessment tool such as MAT01 Calc. While One-click LCA promises a smooth transfer of BIM model information into the assessment tool, it has not yet been explored by the BREEAM expert team.

Table 5 Level of BIM use for BREEAM-NL: Literature vs Practice

Type of credit	Possible BIM Use (Literature)[1]	Actual BIM Use (Practice)
Type 1	Full automation	Manual assessment
Type 2	Partial automation	Manual assessment
Type 3	Full automation	Semi-manual assessment[2]
Type 4	None; needs human input	None; manual assessment

1. *Refers to the highest possible level of BIM use for GBA*
2. *In ENE & MAT categories, only one credit falls under Type 3- MAT01. One-Click-LCA is a tool that can import the BIM data automatically and calculate environmental impacts. But since not all the data is stored in BIM models, there is still some manual work required in this workflow at the moment.*

4.5 Barriers to BIM implementation

Despite the evidence that BIM can streamline the process of compliance verification and allow for efficient change management, it is not yet implemented in practice for BREEAM projects. Interview analysis of the involved actors shed some light on this aspect, and the following challenges to BIM implementation have been identified.

1. **Knowledge gap:** The BREEAM consultant team is not aware of the possibilities with BIM for BREEAM(-NL). BIM related tasks are not usually a part of their job activities and therefore, they lack general awareness about BIM applications. And the BIM team of the organization is unaware of the requirements and workflows of BREEAM-NL projects. Interviewee (B9) expressed that although BIM ambitions and goals are laid out annually, the implementation is lagging behind because the BIM department is unaware of the exact work processes and needs of the other teams.

2. **BIM Training:** Some interviewees (B2 & B9) expressed that although they are aware of some of the latest BIM developments, they do not know how to use these new tools. Training lessons or workshops are needed to use these BIM tools on a regular basis. This is in line with the findings from Alsehrawy et al., (2020).

3. **Information exchange**: As with any BIM use case, availability and quality of information models is crucial. BIM Models are not structured well. They're used more like a 'dumping tool' (B1). Majority of the information is exchanged through 2D drawings currently. Although a BIM protocol is usually drawn for any project, BREEAM expert team is not included in these agreements.

4. **External dependency:** When it comes to the use of BIM, progress cannot be made separately. Cooperation from external parties is crucial as without that, the technical infrastructure for a better BIM use would exist, but the information needed to use them is absent (B4, B5, B6). Therefore, it is important that the benefits of using BIM are known to/ shared with external stakeholders as well

and mechanisms to ensure cooperation must be explored. Some of these issues were discussed in Ayman et al. (2018).

5. **Unavailability of commercial software:** On the technological front, the biggest barrier to widespread use of BIM for green certification assessments in the unavailability of software tools to accomplish this (Lu et al., 2017 & Alsehrawy et al.,2020). Although majority of the academic research on this topic has been technology-driven, currently there is no commercial tool that can fully automate the assessment of BREEAM-NL credits based on the information retrieved from BIM models.
   Automation scripts to do the assessment tasks can be developed by the project teams themselves, but given the diversity of the certification schemes based on the building function, project type and even the year of construction, it will be a high investment of time and money.

6. **Interoperability:** It is a major issue for performance analyses. The BIM models often are not supported by the performance analysis tools, and even if they did, they're overloaded with unnecessary information that is not required for analysis purposes. Therefore, the models are mostly made from scratch again. This gap has also been confirmed in several literature works such as Ansah et al., (2019) and Lu et al., (2017).

4.6 Summary

This chapter summarized results from the second phase of the research. In this phase, the actors typically involved in a BREEAM-NL assessment process were interviewed. They were asked about the typical steps in the assessment process, their roles and responsibilities, communication patterns with other stakeholders and the perceived challenges. They were also questioned about the extent to which they use BIM, and their knowledge on how BIM could be useful for BREEAM-NL assessments. BIM experts from the case study organization were also interviewed to gain understanding about the level of BIM implementation and acceptance at an organizational level. The results from the interviews also shed light on the challenges and barriers associated with the implementation of BIM based GBA. These results help in answering the sub research questions 2 and 3.

SQ 2: To what extent BIM is currently being used in the BREEAM-NL assessment process?

Currently, in the context of BREEAM-NL assessments, BIM models are not actively used. Information required for the calculations associated with BREEAM-NL credits are obtained primarily from 2D drawings. For most credits, the project team uses excel tools either made by them or provided by the DGBC for assessments. Gathering the input required for these tools is often the most challenging part. Although 3D models & 2D drawings are often shared in a Common Data Environment, the information is unorganized and therefore, email based communication is opted for information requests.

SQ 3: How does the industry situation compare to the promised potential of BIM for green building assessments? What are the reasons for the gap?

To summarize the differences between the possibilities of BIM for BREEAM-NL credits and the actual implementation in practice:

1) The assessment of Type 1 & 3 credits can be completely automated using BIM provided that the input information is added in the BIM models. In practice, the assessment method is fully manual.
2) The assessment of Type 2 credits require a transfer of BIM model data to BEM tools and this requires some human interference. Therefore, the assessment can only be partially automated for these credits. However, in practice, the assessment method is completely manual and the energy models are built from scratch due to interoperability issues.

The reasons for the gap between possible and actual level of BIM use for BREEAM-NL assessments are three-fold: 1) On the technological front, the lack of commercial software that can directly automate assessments and the poor interoperability between the BIM authoring and performance analysis tools are hindering BIM based GBA in practice. 2) At the BREEAM-NL team level, there is a lack of awareness about the possibilities of BIM and how to use them in practice. 3) At a project level, the dependency with the external stakeholders for inputs for assessments and aligning the information exchange formats with the requirements of the BIM based automation tools is challenging.

Chapter 5

BIM implementation strategy

The ideal end goal and vision for BIM based GBA is laid out in the literature. In this stage, all the information required for the assessment of BREEAM-NL credits will be stored in the predefined formats in BIM models and the verification of compliance can be done in an automated manner. All the project teams will have real-time feedback on the status of BREEAM-NL compliance.

However, this end goal cannot be achieved at once. It requires incremental changes in Technology, Policy and Process fields as with the case of any BIM adoption. This Chapter will first discuss these preliminary conclusions based on literature and case study interviews. Then, what the intermediary stages in BIM-based BREEAM-NL assessment method will look like is discussed through a BIM maturity matrix. Furthermore, methods to identify the current BIM maturity stage pertaining to BREEAM-NL assessments will be proposed and steps to move to higher maturity levels will also be described. Research questions expected to be answered at the end of this chapter:

SQ 4: How can project teams make the best use of BIM for BREEAM-NL?

5.1 Preliminary conclusions

5.1.1 Relationship between BIM Maturity and possible BIM uses

The relevant BIM uses for BREEAM-NL assessments are discussed in Section 3.2. But not every team can take advantage of these uses as the possibility of their application in practice is governed by the level of BIM maturity a team operates at. For example, if a project team is using 2D drawings for design details but uses 3D models merely for visualization, the models do not contain any information to perform automated assessments. The success of a BIM-based GBA is only as good as the information contained in the BIM models.

Therefore the first preliminary conclusion is that the level of applicability of BIM for GBA proportionally increases with the BIM maturity. Starting from pre-BIM, where 2D drawings are no more than a design reference, the BIM uses increases up to fully automated assessments at Stage 2.

5.1.2 Considerations for implementation – Technology, Process & Policy

Having the technical infrastructure that enables the automation of GBA is not enough to ensure its application in practice. Typically, the role of BREEAM-NL experts does not include a lot of interaction with BIM. Therefore, they need to be first educated on the possibilities with BIM and how to use these automation tools. While BREEAM-NL expert team is the one making the assessments, the information has to be fed into the BIM models by external parties. The guidelines for modeling and information exchange have to be specified in detail to ensure accurate results. This would result in additional time investments into modeling, which can only be possible with the support of the client and changes in contractual agreements. So the second preliminary conclusion that can be drawn is that an implementation strategy for BIM based GBA must discuss action steps across three fields: Technology, Process and Policy.

These two conclusions will form the theoretical basis for the design of the BIM implementation strategy and the recommendations proposed at the end of this research.

5.2 BIM Maturity stages for BREEAM-NL

On a broad scale, five BIM maturity stages for BREEAM-NL assessment can be described similar to the classification provided in Section 3.1.2. The sub-criteria defined for each BIM field was adapted from some of the commonly used BIM maturity models such as Succar et al., (2009), Siebelink et al., (2018) and Liang et al., (2016). The sub-criteria defined in these models is filtered to choose the ones relevant in the context of BREEAM-NL assessments. It must be noted that these stages do not represent the status of organization's overall BIM maturity, but only specific to BREEAM-NL assessments.

1. Pre-BIM: In this stage, information required for BREEAM-NL assessments is shared with the expert team through 2D drawings. Collaboration between stakeholders is limited and the design process is linear.

2. Stage 1: Manual assessment: In this stage, information pertaining to BREEAM-NL credit requirements is added to the BIM models, but the data sharing mechanisms still follow a mix of 2D drawings and 3D models. Communication between stakeholders is unidirectional and often through emails.

More concretely what this means to the types of BREEAM-NL credits established in Section 3.3 is:
1. For Type 1 & 3 credits, information is only partly available in the BIM models. Therefore, the missing information is added manually in the calculation tool/ excel sheets.
2. For Type 2 credits, no guidelines are in place to ensure an export-ready BIM model and therefore, energy models are built from scratch.

3. Stage 2: Partial Automation: The purpose of BIM models goes beyond mere visualization of data. Additional features such as scheduling and estimation are actively used and therefore, basic BIM guidelines are established to ensure the delivery of this information.

More concretely what this means to the types of BREEAM-NL credits established in Section 3.3 is:
1. For Type 1 & 3 credits, all the information required for assessments will be available in the BIM models, as it was a part of the established BIM guidelines. However, if the information required is spread between different project phases, due to the non-involvement of construction parties in the early stages of design, information needed to make preliminary assessments will have to be entered manually.
2. For Type 2 credits, Model View Definitions (MVD) are integrated in the BIM protocol to allow for a seamless transfer to energy modeling tool. But, as in the case of Type 1 & 3, some information such as HVAC component details or glazing details will not be available at the initial design phases. Therefore, human input is needed to make educational guesses in order to conduct energy performance analysis.

4. Stage 3: High automation: Bi-directional information sharing occurs through project specific network-based platforms such as BIM360. The BIM models become n-dimensional, meaning they contain information beyond the design aspects such as constructability properties or green product declarations etc.

More concretely what this means to the types of BREEAM-NL credits established in Section 3.3 is:
1. For Type 1 & 3 credits, all the information required for assessments will be available in the BIM models at any design stage. The assessments can therefore be completely automated.
2. For Type 2 credits, Model View Definitions (MVD) include information from all disciplines as the design process becomes integrated and concurrent. However, due to the interoperability issues still faced in the transfer of BIM models to BEM tools, the process still requires some manual input to make adjustments to the imported model.

5. Post-BIM/: The ultimate vision for a BIM-based BREEAM-NL assessment process is characterized by: 1) Integrated planning together with all disciplines to achieve certification ambitions 2) Complete automation of the assessment of the compliance with credit requirements 3) Real-time feedback on the status of the project's BREEAM-NL compliance 4) Active responsibility and involvement of all the stakeholders in monitoring BREEAM-NL progress. However, the current technical possibilities do not allow for a complete automation of the Type 2 credits, as some level of human input is required due to interoperability issues between BIM and BEM tools.

Each of these BIM stages can be characterized based on a set of sub-topics in technology, process and policy fields. Table 6 provides an overview of the status of each sub-criteria at different BIM stages. This classification is further elaborated along all the three BIM fields in Appendix G. Post-BIM stage is not included in this matrix as this is a representation of the possible future innovations and therefore, is left with a generic description.

Using this matrix, project teams and organizations can have a clear idea of where they stand in all the three fields and therefore, what the immediate next steps are in the transition to a BIM-based BREEAM-NL assessment.

Table 6 BIM Maturity Matrix for BREEAM-NL

Step set		**Pre-BIM**	**Stage 1: Manual assessment**	**Stage 2: Partially automated assessment**	**Stage 3: Highly automated assessments**
BIM Field	**Sub-domain**				
Technology	Model content (T1)	2D	Mix of 2D & 3D	Detailed 3D design models	Detailed 3D design & construction models
	Hardware support (T2)	NR	Limited hardware support	Sufficient hardware support	Powerful hardware systems
	Software tools (T3)	NR	3D model viewing software programs	Tools for partial automation	Tools for high automation
Process	Information exchange (Pr1)	Paper based	Electronic file based	Federated models in CDE	Integrated models on a cloud platform
	Management support for BIM (Pr3)	NR	BIM Vision for BREEAM-NL projects	Small scale pilot projects	Large scale implementation support
	BIM Training (Po3)	NR	Ad-hoc	Extensive BIM training for target personnel	Structured BIM training for the entire team
	BIM roles (Pr5)	NR	Ad-hoc	Information manager appointed	Internal BIM roles are defined
Policy	BEP	NR	No involvement from BREEAM-NL team	Low level details	Highly detailed

	Contractual (Po2)	NR	Not BIM related	BIM Protocol	Reward mechanisms & risk allocations
	Deliverables (Pr4)	NR	No BIM deliverables for BREEAM-NL	BIM deliverables for pilot credits	Specific BIM deliverables for all credits

NR = Not Relevant for this stage

5.3 BIM stages vs benefits for BREEAM-NL assessments

The extent to which the use of BIM can address the challenges identified in the BREEAM-NL assessment process (refer Section 4.3) depends upon the BIM stage. As a project team moves towards the higher maturity stages, the BIM model uses relevant for the BREEAM-NL assessment process and the consequent benefits increase. Figure 19 shows the relationship between BIM stages and benefits for BREEAM-NL assessments.

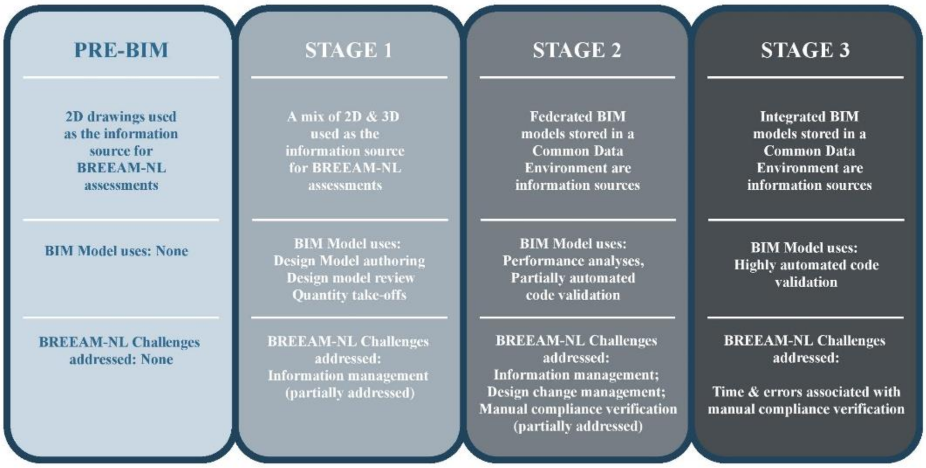


Figure 19 Relationship between BIM Maturity stages and benefits for BREEAM-NL assessments (Own analysis)

At stage 1, challenges associated with information management are only partially addressed. This is because, the availability of automatically coordinated views in 3D provides more accurate and reliable disciplinary information. But due to the absence of a Common Data Environment (CDE) and the asynchronous nature of communication, gathering interdisciplinary data for the assessment of credits is still a challenge. At Stage 2, due to the presence of a CDE and associated data delivery guidelines, the process of gathering reliable, up-to-date information becomes smoother. At this stage, the BIM models also include non-graphical information and therefore, it makes the automated assessments possible for a few Type 1 & Type 3 credits.

Stage 3 involves an integrated project approach where all the activities and decisions of design, construction and operation phases are planned concurrently (Succar, 2009). Therefore, all the information needed to automate the credit assessments at any point of the building's life cycle will be possible. Since the current technology innovations still require some level of human intervention in the BIM based performance analysis process, Type 2 credits cannot be fully automated. But a high level of automation for code compliance can be achieved at BIM stage 3 and the challenges associated with manual compliance verification i.e., the associated time and possibility of errors is greatly reduced

5.4 Steps towards higher BIM maturity

To move across the BIM Maturity axis from Pre-BIM to IPD, intermediary steps are needed for each stage. Once a project team or organization has identified their maturity, the next action is to implement a set of recommended steps in order to move to a higher maturity level. These steps for each stage are named as shown in Figure 20 and are elaborated below. Steps for the transition phase D are not included as the stage is a representation of future possibilities and therefore, is not concretely defined.

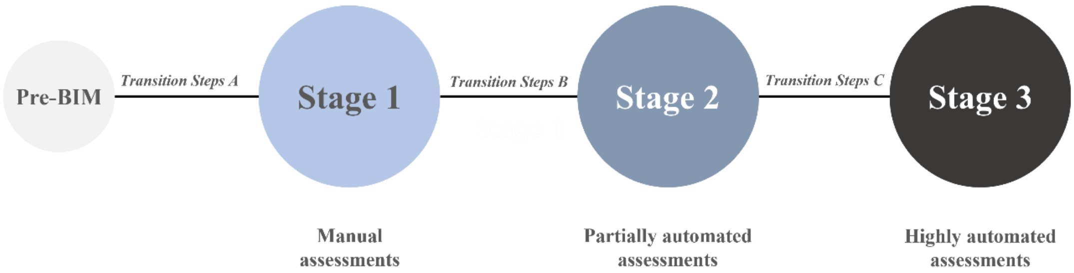


Figure 20 Transition steps to higher maturity stages

5.3.1 Transition Steps A

1. **Technology**: Acquire software systems to view and collect information from 3D models shared by external stakeholders.
2. **Process**: a) Set-up electronic file sharing guidelines with external stakeholders; b) Identify BIM uses for BREEAM-NL assessments and prepare a strategic plan for its implementation
3. **Policy**: Policy agreements for the purpose of BIM-based BREEAM-NL assessments are not relevant for this stage as the transition from CAD to BIM is not yet done.

5.3.2 Transition Steps B

1. **Technology**: Develop technical infrastructure for automating the assessment method for some of the most time-consuming BREEAM-NL credits from Type 1 & 3 (Refer Chapter 3 for the inventory of Type 1 & 3 credits).
2. **Process**: a) Test the automated assessment methods in pilot projects with the whole team
   b) Identify the personnel primarily responsible for BIM tasks and set up training programs with the help of BIM department
   c) Appoint an information manager responsible for coordinating with the external teams for information collection and quality checking.
3. **Policy**: a) Include BREEAM team's BIM requirements and deliverables in the protocol document.
   b) Identify the modeling requirements for the successful implementation of the automation tools and include it in the BIM Execution Plan
   c) Identify the list of BIM deliverables required for the implementation of this automated workflow

5.3.3 Transition Steps C

1. **Technology**: Develop technical infrastructure for automating the assessment method for all BREEAM-NL credits from Type 1 & 3 (Refer Chapter 3 for the inventory of Type 1 & 3 credits); Identify the energy modeling tool with the best interoperability support with BIM data

2. **Process**: a) Commit resources for the large scale implementation of BIM for BREEAM-NL assessments and associated training
   b) Identify and define internal BIM roles required for a BIM-integrated assessment process
   c) Prepare a general BIM awareness and training program for the entire BREEAM-NL team with the help of BIM department
3. **Policy**: a) Include BIM related risk allocations and reward mechanisms deliverables in the contract.
   b) Include all the information requirements and MVDs in the BEP
   c) Identify the list of BIM deliverables for all Type 1 & 3 credits and define MVDs for Type 2 credits

To reach the consequent BIM stage and successfully reap its benefits, recommended actions in all the three BIM fields have to be implemented. The transition may be initiated from any field but the corresponding steps in the other two fields have to be followed to reach the next BIM stage.

5.5 Effort to move to higher BIM stages

Efforts to be made across each BIM field in different transition phases is shown in Figure 21. Transition phase A i.e., from pre-BIM scenario to BIM stage 1 involves the replacement of 2D drawing software programs with 3D object-based modeling tools such as REVIT, ArchiCAD etc. But the working process and the communication patterns remain the same as the previous stage. Therefore, high level of Technology changes, but relatively low levels of policy and procedural changes.

Transition phase B i.e, from maturity stage 1 to stage 2 involves the practice of implementing more advanced uses of the 3D modeling tools and therefore, technological changes are not so radical as compared to the previous transition. The effort that goes into technological changes will reduce even more if there were a commercial software program available for automated BREEAM-NL assessments, however since that’s not the present case, project teams will have to develop their own technical infrastructure to automate the assessment tasks. During this phase, communication starts to become more organized and model-based and therefore, policy and process fields witness higher levels of changes in this transition phase.

Transition phase C i.e., from maturity stage 2 to stage 3 is not just an improvement in the use of BIM tools but rather a switch to a new way of working (Bataw & Boyd, 2013). As noted by Succar (2009), the perquisite for BIM stage 3 implementation is the maturity and availability of the network and software solutions that can facilitate the real-time integration of interdisciplinary information. In addition, the promotion of network based integration also requires major reconsideration in procedural and contractual relationships. For example, in the case of stage 3 BIM for BREEAM-NL assessments, implementation requires significant increase in the modeling efforts from external project stakeholders whereas the primary benefits of this advanced use of BIM (If implemented solely for the purpose of automated BREEAM-NL assessments) will be mainly reaped by the BREEAM-NL expert team and the client. Therefore, to ensure successful implementation, legal agreements will have to be made regarding compensations for additional detailing, information ownership rights, risk allocation etc.

Figure 21 Effort per each transition stage

Based on the achievable benefits for BREEAM-NL assessment process at each BIM stage and the effort that goes into the transition, it can be argued that the progression to BIM stage 2 might be the most lucrative. Further research is required on this matter to draw definitive conclusions. It goes without saying that the benefits arising from BIM stage 3 will significantly improve the AEC processes and will be beneficial to all stakeholders. However, this change cannot be initiated by the BREEAM expert team alone and implementation will only be possible when the industry is ready for this evolution. For technology driven organizations, it is also possible to take a revolutionary approach and make a direct switch to Stage 3. But the effectiveness of this approach would require further research.

5.6 Summary

The analysis of the data collected from literature and interviews indicated that the transition to a BIM-based workflow in practice occurs gradually as opposed to a dynamic shift to a fully sophisticated BIM implementation. BIM Maturity models can serve as useful tools in providing some understanding on the stages of development of BIM in practice and roadmap to these stages. By mapping the development stages of BIM across its three interlocking fields of Technology, Policy and Process, a BIM Maturity Matrix for BREEAM-NL assessments was proposed in this chapter. For each field, sub-domains were defined in order to elaborate their characteristics further.

Based on the previous studies on BIM maturity, five development stages are identified namely Pre-BIM, Stage 1- Manual assessment, Stage 2- Partially automated assessment, Stage 3- Highly automated assessment and lastly Post-BIM/ Integrated Project Delivery. By mapping the maturity stages to the BIM fields and their sub-domains, a detailed maturity matrix for BREEAM-NL assessments was arrived at. The advantages that come with each BIM stage and the challenges in BREEAM-NL assessment process that it addresses was also discussed.

Based on this matrix, project teams or organizations can evaluate their current maturity stages. For each transition phase, a set of recommended actions are provided that can be adopted in order to increase the maturity level of BIM implementation for BREEAM-NL projects. These recommendations are specified for each BIM field, and it must be noted that each transition relates to a different set of actors. Technology transition can be facilitated by commercial software developers or intra-organizational BIM technology enthusiasts. Process-related transition can be initiated by the project team but requires support and collaboration from the external project teams. Policy-related transition can be facilitated by clients and industry as a whole.

There are two possible approaches to progress along the maturity levels: Taking an evolutionary approach and progressing gradually through each stage or by taking a revolutionary approach in one dimension such as technology and elevating the other dimensions in response to that. The intent of this thesis study was to aid a BREEAM-NL expert team which is at the nascent stages of BIM use, in performing the assessment tasks more efficiently. The focus therefore, is to provide a solution in response to the current industry context for the case study organization. For this reason, the author’s recommendation is to follow the recommended steps for transition in a gradual manner. However, should the project circumstances and resources allow, it is very much possible to take a revolutionary approach.

Chapter 6

Case study

Based on the BIM Maturity Matrix proposed in Chapter 5, the current maturity stage of the case study team is assessed. The insights gathered from the interviews in the second research step were used to make this assessment. The results of this assessment is explained in Section 6.1, followed by the recommendations proposed for the project team. The recommendations proposed in this research are divided into two: *Level 1: Recommendations aimed at the whole certification process in general* and *Level 2: Detailed recommendations using MAT05 credit as an example.* The results of this Chapter will partly help in answering the fifth sub-question:

SQ 5: How does the proposed strategy help BREEAM-NL project teams?

The questioned can be fully answered after assessing the validity of the results. Therefore, the answer to this sub-question will be discussed at the end of Chapter 7.

6.1 Current maturity stage

Based on the results from the initial interviews, the current maturity stage of the BREEAM-NL project team was assessed. It was found that overall, the team stands at BIM stage 1. The results are summarized in Table 7. The assessment for each sub-criterion and the reasoning behind the score is provided below.

6.1.1 Technology

1. Software tools: The use of BIM tools in the team is limited to model viewers and performance analysis programs in a few cases. With regards to the compliance assessments, excel based tools are predominantly used (Interviewees B3, B5, B6, B8). For this reason, the team stands at **Stage 1** in this criterion.

2. Hardware support: Organization wide hardware provisions adequately support the use of BIM software applications. However, on a team level, BIM is not a consideration for further investments or planning maintenance and upgrades. Therefore, the team is assigned **Stage 1** in this criterion.

3. Data format: Mostly 2D drawings. Although architects and MEP designers provide their disciplinary 3D models, for BREEAM-NL assessments and documentation 2D drawings remain the primary data exchange formats (Interviewees B1,B2.B3,B4,B5,B6 & B8). This is mainly because the 3D models do not include sufficient details necessary for the assessments. Therefore, the team is assigned **Stage 1** for this criterion.

6.1.2 Process

1. Information exchange: All project partners share their disciplinary models and 2D drawings through a Common Data Environment. In some of the recent projects, the team started to use BIM360 as that was required by the client. While the design teams make use of this platform for coordination of the individual models and better collaboration, the BREEAM-NL team does not actively use this platform for communication or issue management. Therefore, the team is assigned **Stage 1** for this criterion.

2. Management support: BIM vision and annual goals are set up at the organizational level. Although the aim was to allocate a BIM coordinator for each team responsible for overseeing the BIM goals and implementation plans, it is not yet seen in practice (Interviewee B9). So the BREEAM-NL expert team does not have a BIM champion within the team. Interview results indicated that at the managerial level, there is an open interest in moving towards a more BIM integrated workflow provided a good business case is made for the change (Interviewee B3). But currently, BIM vision for certification projects is absent. Therefore, the team stands at **Stage 0/ Pre-BIM** for this criterion.

"In a lot of projects we see a lot of talk about BIM integration and automation, but in the end it does not really help us. For example, there is increasing interest in BIM360, but I don't really know the benefit for BIM360 as compared to SharePoint/ OneDrive. When proposing BIM implementation plans, it is important to explain the benefits BIM would provide for the team. " – Interviewee B3

3. BIM Training: There are only a few members of the team that actively use BIM (not for automated assessments, but for performance analyses). There are no established BIM training programs for the team or even these active BIM users. Support is provided by the BIM department when required, but the requests have to be initiated by the BREEAM-NL team members (Interviewee B9). Therefore, the team is assigned **Stage 1** for this criterion.

4. BIM Roles: Currently the use of BIM is not an active part of the assessment/ documentation process. Therefore no defined BIM roles exist at the moment, but rather the use of BIM is ad-hoc in nature. Therefore, the team is assigned **Stage 1** for this criterion.

6.1.3 Policy

1. BEP: The interview results indicated that the BREEAM-NL expert team members are not aware of the meaning and the contents of a BIM Execution Plan in any of the projects they were involved in. Analysis of the project documentation revealed that although BEP exists for many projects, BREEAM-NL team is not considered a member of that agreement. Therefore, the team is assigned **Stage 1** for this criterion.

2. Contractual: Currently, BIM-related contractual agreements do not exist between the client and the BREEAM-NL expert team . Although BIM protocol document exists for most of the projects aiming for BIM level 2 collaboration, automated sustainability assessments is not a part of the BIM goals. Therefore, the team is assigned **Stage 1** for this criterion.

3. Deliverables: The team has assigned responsible stakeholders and their list of deliverables for each credit in the BREEAM-NL certification. However, the format of information delivery is left open and not necessarily related to BIM. For this reason, the team is assigned **Stage 1** for this criterion.

Table 7 Current BIM Maturity assessment

BIM Field	Sub-criterion	Maturity score
Technology	Software tools	1
	Hardware support	1
	Data format	1
Process	Information exchange	1
	Management support	0
	BIM Training	1
	BIM roles	1
Policy	BEP	1
	Contractual	1
	Deliverables	1

6.2 Level 1 Recommendations

Based on the results from the current BIM Maturity assessment, the immediate next step for the case study company is to initiate the transition to Stage 2. This involves a set of actions across all the three domains of Technology, Policy and Process. The recommendations proposed in this section (See Figure 22) are Level 1 i.e., aimed at the overall certification process.

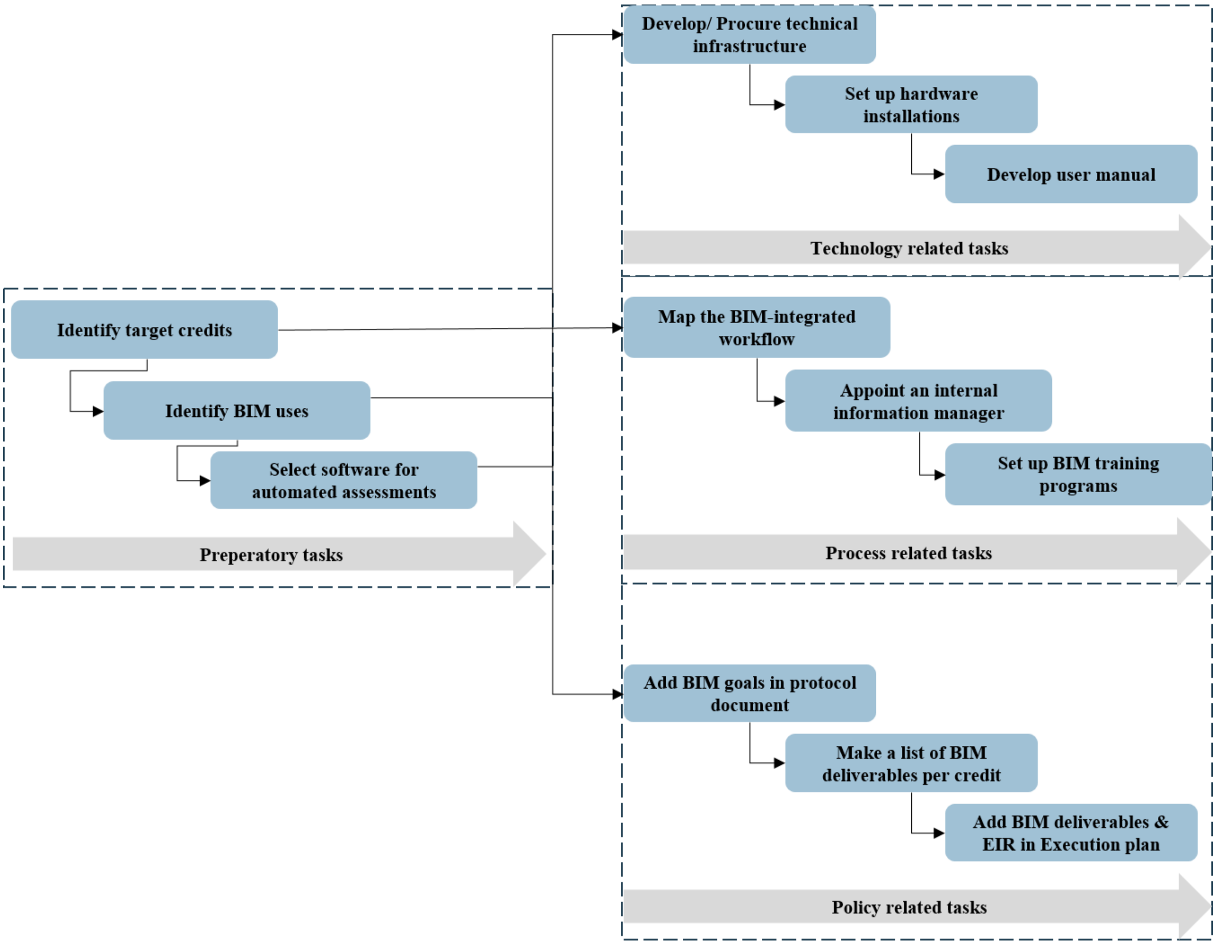


Figure 22 Level 1 recommendations (Own image)

6.2.1 Preparatory tasks

Before initiating the implementation steps to BIM stage 2, a set of preparatory tasks are recommended as seen in Figure 23.

1. Select target credits: The first step is to identify the list of target credits. The target credits for this stage are only the critical credits which are either the most time-consuming or risky ones. Automating these tasks alone will be a big-win for the team. In Energy and Materials, ENE01, ENE04, ENE05, MAT01 and MAT05 are the most critical, time consuming credits as expressed by the BREEAM experts interviewed. This list of the target credits must first be extended to the rest of the categories in the assessment scheme.

2. Identify BIM Uses: The target credits must then be mapped with the applicable BIM model uses. The list of BIM uses given in Appendix A can be used as reference for this step. For the target credits identified in Energy and Material categories, the applicable BIM uses are listed below in Table 8.

Table 8 Relevant BIM uses for target credits

S.No	BREEAM-NL credit	BIM uses
1	ENE01	Energy performance analysis Automated code compliance
2	ENE04	Lighting equipment schedule Lighting analysis Automated assessment
3	ENE05	Energy performance analysis Automated code compliance
4	MAT01	Quantity take-off Environmental impact analysis Automated code compliance
5	MAT05	Quantity take-off Automated code compliance

3. Selection of software tools: Since no commercial tools are currently available to automate the BREEAM-NL assessment tasks, the technical infrastructure has to be developed by the organization themselves. As shown in Section 3.3.4, there are several integration approaches and software tools to automate the assessment process.

The first step therefore, is to select the best suited software platform for the organizational context. This can be done by performing a Multi-Criteria Analysis (MCA). The important criteria for BIM adoption and their weights were arrived at based on the interview results. The different solution options identified from literature were scored against these criteria. The details of this MCA is provided in Appendix H. The results indicated that a REVIT based plugin is the best suited software tool for the given context.

The software choice greatly varies across organizations, project teams and even time. So the framework proposed for software selection can be used to constantly monitor the suitability of the tools in use and for decision making for software upgrades or changes.

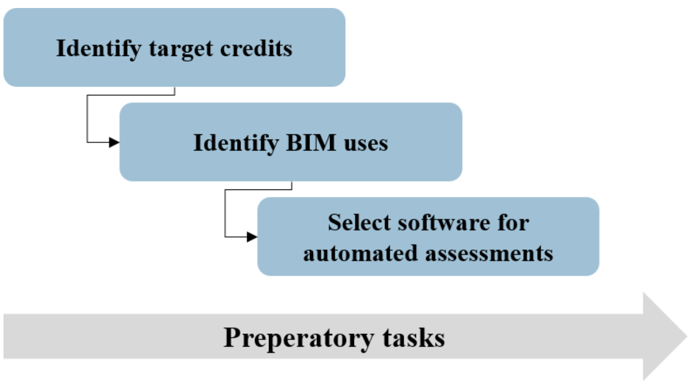


Figure 23 Level 1 recommendations: Preparatory tasks (Own image)

6.2.2 Technology

The transition from Stage 1 to Stage 2 BIM involves low-medium level of technological interventions. The recommendations shown in Figure 24 are related to selection and development of software infrastructure and setting up the necessary hardware support to use these tools.

1. Development/ Procurement of automation tools: Currently there is no readily available commercial tool for automated assessments, therefore, the tools have to be developed internally. The aim of BIM stage 2 is to automate the assessment process for the most time consuming Type 1 & 3 credits. A list of these credits within ENE & MAT categories is provided in Section 3.2. The input requirements for these credits can be obtained from the excel-based calculation tools that are currently in use. The inputs are primarily based on the geometric information that can be automatically retrieved from BIM models. With the help of BIM and ICT department, automation scripts that can extract this information from BIM models and automatically feed it into the calculation tools must be developed.

2. Hardware setup: After the development of automation tools, the necessary hardware installations must be done on the office systems. A hardware maintenance and upgrade plan must be developed with the assistance of the BIM & ICT departments.

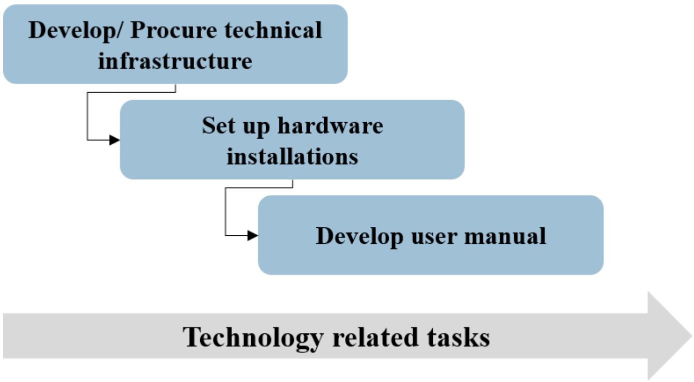


Figure 24 Level 1 recommendations: Technology-related tasks (Own image)

6.2.3 Process

The transition from Stage 1 to Stage 2 involves high level of changes in the process field. The recommendations provided in this domain, as seen in Figure 25 are elaborated below.

1. Process mapping: The first recommendation in the process field is to make a process map of the BIM-integrated workflow for the selected target credits. Process maps help the project team members understand the BIM-induced changes and the associated requirements better. Based on the process map, new BIM related roles and responsibilities of various stakeholders can be identified. These responsibilities must be communicated at the BREEAM-NL kick-off meeting.

2. Appoint an internal information manager: If the assessments are to be made solely based on the information in BIM models, adequate measures must be taken to ensure the quality, reliability and usability of the received information. For this purpose, the recommendation is to appoint an internal information manager that will be responsible for coordinating with the BIM managers of each project, ensuring the addition of BIM requirements in the project's BEP and is also responsible for information management and quality checking.

3. Set up BIM training programs: In order to successfully implement the developed BIM based assessment tools in practice, the project team members responsible for the selected credits must be provided with adequate training. With the help of the BIM department, these knowledge sessions must be arranged.

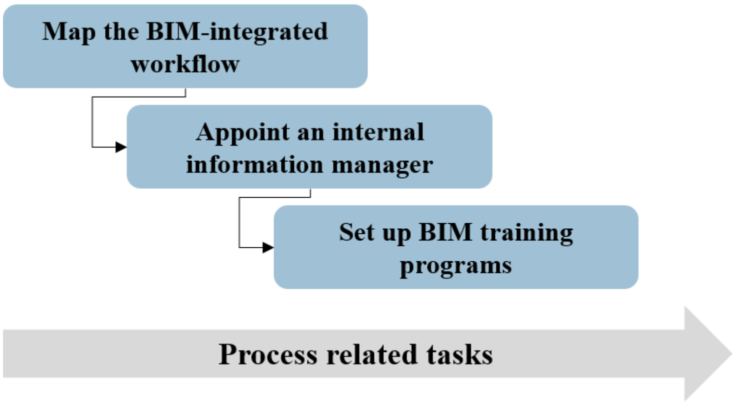


Figure 25 Level 1 recommendations: Process--related tasks (Own image)

6.2.4 Policy

The policy related recommendations help in making necessary BIM related arrangements with the external parties to facilitate automation of the critical credits. The recommendations seen in Figure 26 are further elaborated below.

1. BIM Protocol: The relevant BIM model uses, required level of detail of the BIM models and the associated data drops from stakeholders must be aligned with the requirements outlined in the BIM protocol document. These arrangements must be agreed upon with the client at the beginning of a project.

2. BIM Deliverables: A list of BIM deliverables per each stakeholder per credit must be developed. These deliverables must be in line with the input requirements for the automation tools.

3. BIM Execution Plan: The BIM implementation methods and means of satisfying the client's BIM ambitions are detailed in a BIM Execution Plan. BREEAM team must be an active part of its formulation, ensuring that the relevant information exchanges, stakeholder deliverables and modeling requirements are included in the document.

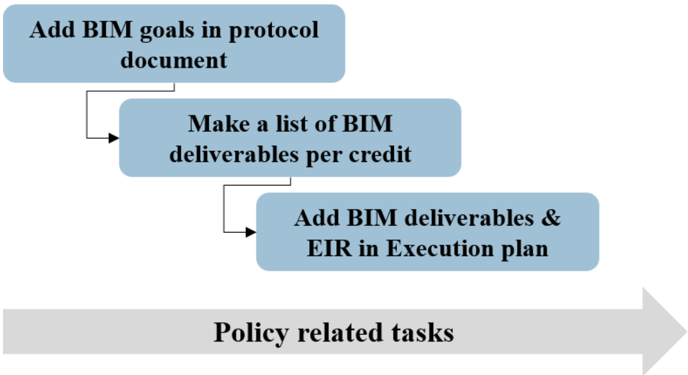


Figure 26 Level 1 recommendations: Policy-related tasks (Own image)

6.3 Level 2 recommendations

6.3.1 Example credit – MAT5

The recommendations proposed are generalized, and meant for the whole certification scheme. To elaborate further on what this would look like on concrete terms, MAT05 credit was chosen as an example. From the interviews in Chapter 4, it was identified that of all the credits in Energy and Material categories, ENE01, ENE05, MAT01 and MAT05 are the most time consuming ones. Therefore, these credits are a part of the critical credits chosen for automation in Stage 2. The reason for choosing MAT05 is because it is one of the simpler credits with regards to the assessment procedure, yet very time consuming. This is a good example to demonstrate how BIM can make some mundane, repetitive tasks more efficient through automation.

According to the BREEAM-NL assessment guideline, a building is divided into 6 main parts depending on the function of the components (See Table 9). To calculate the achievable points for MAT05, the materials used per each building part and their individual volumes must be calculated. Based on the kind of sourcing of the material, the BREEAM-NL guideline prescribes the assignment of '*Tier levels.*' The material names, volumes and Tier levels is fed into the MAT05 calculator provided by the DGBC to arrive at the final number of credits achievable for a project.

Table 9 Material classification for MAT5 calculation

Building Part	Description	Sub-division
A	Foundation & sub-structure	Foundation feet, piles, beams,
B	Internal walls	Internal walls, windows and doors, frames
C	External walls	External walls, windows and doors, frames
D	Roof	Roof and roof openings
E	Load-bearing frame	Columns, beams, lintels
F	Floors	Floor slabs, balcony floors

The input data and assessment process is illustrated in Figure 27. Currently, this is done manually using a REVIT/ IFC file as reference. How this process can be automated using BIM and the recommendations to implement this in practice are discussed in the following sections.

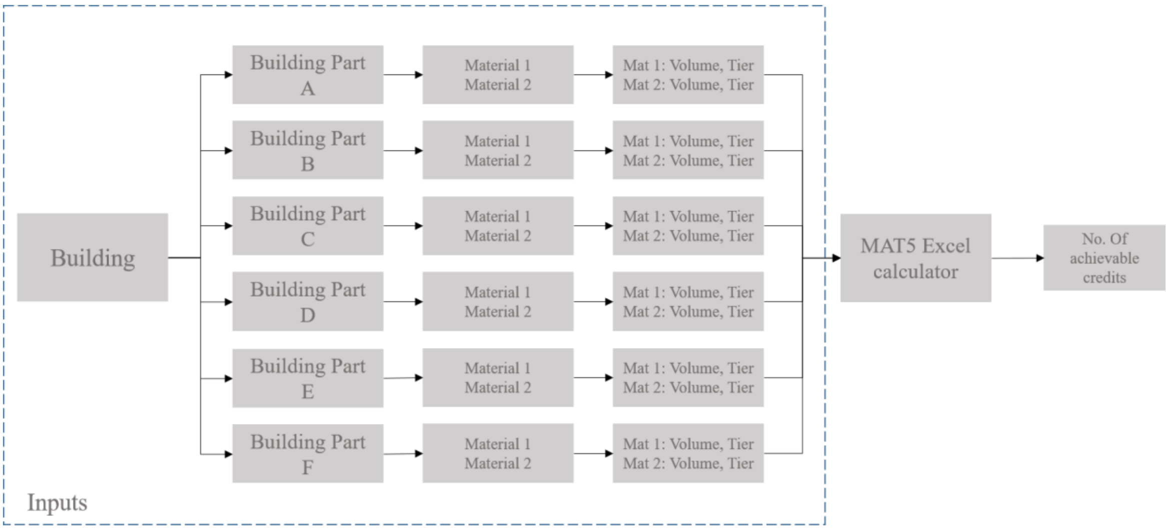


Figure 27 Inputs required for MAT5 assessment (Own image)

6.3.2 Preparatory tasks

The relevant BIM uses for this credit are material quantity take-off and fully automated code compliance assessment. The available software tools for the automation are REVIT based tools/ stand-alone desktop applications that use input from BIM models or a cloud based application using Autodesk Forge. As discussed in 6.2.1 and Appendix H, it was determined that a REVIT based plugin is the best suited software tool for this context.

6.3.3 Technology

Using REVIT API, a custom plug-in was developed that performs the MAT5 calculations based on the mathematic logic used in MAT5 excel sheet provided by the DGBC. The details of development of the prototype are provided in Appendix I.

The plug-in was developed using REVIT 2021 SDK and therefore is currently compatible with REVIT 2021. So this version of the software must be installed on the system in order to use it. (For newer/ older versions, the code can be easily adapted with the help of the BIM department).

6.3.4 Process

The workflow for the assessment is not much varied as compared to the current process for this credit. The only added step is model checking to ensure that STABU element codes and material parameters are correctly assigned in the BIM models.

It is recommended to appoint an internal manager who would be responsible for communicating the modeling requirements i.e., additional material parameter, its naming and scoring method, STABU element codes to the project's BIM manager and the BIM coordinators of external project teams. The Material expert responsible for MAT05 assessment must be provided with some general information about the plug-in, its compatibility, installation requirements and how to use it.

6.3.5 Policy

Accurate material quantification and specification must be included as a BIM goal in the protocol document. The use of STABU element coding and material parameter for sourcing type must be included in the BEP. Two additional parameter for materials namely 'Tier' and 'Insulation Material' is to be included in the Information Delivery Manual. During the kick-off meeting, it is suggested to inform the BIM coordinators from the architect and the contractor teams of the classification of Tier levels.

6.4 Summary

This chapter demonstrated the application of the proposed BIM implementation strategy for the case study team. It was found that the team is currently at BIM Maturity Stage 1 and therefore, the next milestone is partially automated BREEAM-NL assessments at Stage 2. To accomplish this, a set of general recommendations have been proposed. The recommendations are divided into four parts: 1) Preparatory tasks to be done by the BREEAM-NL team before initiating the implementation process 2) Technology related tasks to develop the infrastructure for automation. This can be done with the help of the organization's BIM department. 3) Process related tasks for integrating BIM within the workflow. These are to be carried out at the team level. And lastly 4) Policy related tasks for accommodating the BIM based workflow through agreements with external stakeholders and clients. To elaborate what these recommendations would look like for a credit, MAT05 was chosen as an example. Using REVIT API, a plug-in was developed that can automate the MAT5 calculation. Associated process and policy level changes and action steps are also discussed.

Chapter 7

Validation

Last chapter demonstrated the application of the proposed BIM Maturity Matrix for BREEAM-NL assessments for the case study organization. The current maturity stage of the organization, steps that can be implemented to further the use of BIM and reap the benefits of Stage 2 maturity were also discussed. The last step in a design research is to evaluate the research reasoning and reliability of the results. The aim of this chapter is to discuss the validation methods adopted in this study and the consequent results. The research question expected to be answered at the end of this Chapter is:

SQ 5: How does the proposed strategy help BREEAM-NL project teams?

7.1 Validation process

The aim of the validation process was to determine the feasibility and usefulness of the proposed recommendations. To do so, first the results from the prototype were verified using a case study project and they were compared with the results generated from manual method. Following this verification, semi-structured interviews were conducted with BIM & BREEAM-NL experts from the company to gather their opinions about 1) The usefulness of the research and the proposed recommendations in practice, 2) Feasibility of implementing the proposed actions from an internal perspective (i.e., based on the current capabilities of the organization), and 3) Feasibility from an external perspective (i.e., support from client and other project partners).

A short summary of the research work and the list of interview questions were sent out to the participants a few days before the interview meeting. The list of questions used for validation interviews is given in Appendix K.

7.2 Prototype validation

7.2.1 Case study project

The case study project used for the validation of the prototype is the Innocent factory built on the port of Rotterdam. The project consists of two functions: Factory and the office area. The construction stared in 2019, and the client had a sustainability ambition of a Carbon neutral factory. The project aimed for an Outstanding rating in BREEAM-NL certification. Since the construction began in 2019, the applicable assessment guideline for this project was the BREEAM-NL New Construction and Renovation 2014 v2. To test the prototype, the BIM model of the office part of the project was used.

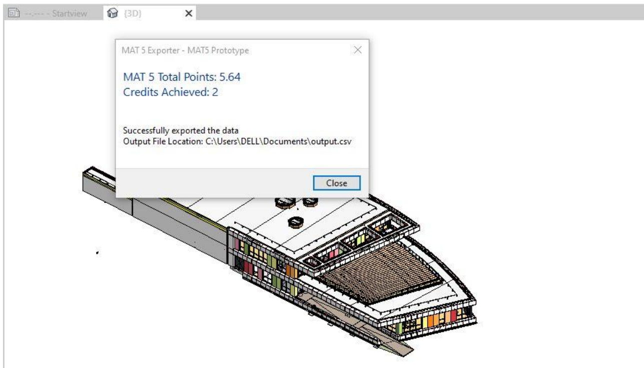


Figure 28 MAT5 Prototype screenshot

The REVIT model of the office part of the project was downloaded and the MAT5 plugin was tested. Within 30 seconds, results were generated by the plug-in as shown in Figure 28.

7.2.2 Validity of results

Figure 29 shows the report generated by the plug-in. To test the accuracy of the results, the material quantities were first manually calculated using the Material take-off option in REVIT. The results were summed up and grouped based on the classification provided by DGBC. The results from both methods matched for all items except for 4. These difference occurred because the REVIT take-off option does not support certain element categories such as curtain wall mullions, wall sweeps etc. (*Missing Categories in Multi-Category Material Take-off*, 2017). These items were checked manually to verify the results.

Then, these values were entered into the excel tool for MAT5 provided by the DGBC. The results from both methods, as shown in Table 10, match. The calculation time was reduced from an hour to 30 seconds. The comparison of the results from both methods and screenshots of the credit calculation in MAT5 tool method are included in Appendix J.

Building Part	Material	Total Volume	Tier 1 Volume	Tier 2 Volume	Tier 3 Volume	Tier 4 Volume	Points
B	aluminium mullion	1.72	0	0	1.72	0	
B	Aluminum_grey	0.3	0	0	0.3	0	
B	Glass_clear_transparent	8.21	0	0	8.21	0	
B	Wood_white_interior windows	3.44	3.44	0	0	0	
B	PVC Flexible	0.32	0	0	0	0	
B	HPL_panel_sanitairy partion walls	1.22	0	0	0	0	
B	sand-lime stone	52.41	0	0	0	52.41	
B	metal (ESP)	0.04	0	0	0	0	
B	air	5.33	0	0	0	0	
B	gypsum_board	55.98	0	0	0	55.98	
B	Wood_white_interior doors	5.79	5.79	0	0	0	
B	BUILDING PART_TOTAL	134.76	9.23	0	10.23	108.39	1.218676
C	concrete_precast	4.52	0	0	0	4.52	
C	glass_facade panel_green_1	0.35	0	0	0	0.35	
C	glass_facade panel_red_1	0.32	0	0	0	0.32	
C	glass_facade panel_yellow_1	0.3	0	0	0	0.3	
C	Wood_plywood	5.8	5.8	0	0	0	
C	Glass_clear_transparent	11.52	0	0	11.52	0	
C	aluminum_facade_cassettes_white	2.57	0	0	2.57	0	
C	hardwood decking boards	0.17	0.17	0	0	0	
C	cement_back plate_glass panel	10.59	0	10.59	0	0	
C	aluminum_windows_external	11.39	0	0	11.39	0	
C	sand-lime stone	58.68	0	0	0	58.68	
C	glass_facade panel_red_2	0.31	0	0	0	0	
C	glass_facade panel_red_3	0.35	0	0	0	0	
C	glass_facade panel_green_2	0.31	0	0	0	0	
C	glass_facade panel_green_3	0.32	0	0	0	0	
C	glass_facade panel_yellow_2	0.28	0	0	0	0	
C	glass_facade panel_yellow_3	0.31	0	0	0	0	
C	Wood_white_interior doors	0.68	0.68	0	0	0	
C	BUILDING PART_TOTAL	108.77	6.65	10.59	25.48	64.17	1.420957
D	Glass_clear_transparent	0.34	0	0	0.34	0	
D	aluminum_windows_external	0.03	0	0	0.03	0	
D	aluminium dakbedekking	3.38	0	0	0	0	
D	Gorter_Material 1	0.17	0	0	0	0	
D	Gorter_Material 2	0.11	0	0	0	0	
D	BUILDING PART_TOTAL	4.03	0	0	0.37	0	0
E	steek (stair)	0.05	0	0	0	0	
E	Wood_common	2.21	2.21	0	0	0	
E	steel_galvanized	2.64	0	0	0	0	
E	steel_stainless	0	0	0	0	0	
E	BUILDING PART_TOTAL	4.9	2.21	0	0	0	0
F	Wood_common	2.96	2.96	0	0	0	
F	hardwood decking boards	9.52	9.52	0	0	0	
F	BUILDING PART_TOTAL	12.48	12.48	0	0	0	3
MAT 5 Total Points							5.639633
Credits Achieved							1

Figure 29 Results from MAT5 plug-in

Table 10 MAT5 Plug-in results vs Manual assessment results

	BIM-based results	Manual method results
Building Part A	NA	NA
Building Part B	1.218676	1.22
Building Part C	1.420957	1.42
Building Part D	0	0
Building Part E	0	0
Building Part F	3	3
Total Points	5.639633	5.64
Achievable credits	1	1

7.3 Expert interviews

It was decided to conduct the validation interviews with BIM and BREEAM-NL experts from within the organization. The reason for not choosing external experts is because the recommendations proposed are tailored for the organizational context and therefore internal members are deemed more suitable for validation. 3 BREEAM-NL experts and 2 BIM experts were chosen for the interviews. Table 11 provides an overview of their roles and experiences. The results from these talks are summarized in the following sections.

Table 11 Overview of Validation interviewees

Interviewee code	Current role	Experience in the organization
B1	BREEAM-NL project manager	20 years
B2	BREEAM-NL project manager	5+ years
B4	Material Expert	2+ years
B9	BIM Manager	13 years
B12	BIM Expert	5 years

1. Internal feasibility: In general all the experts agreed that the recommendations provided are feasible for implementation from an internal perspective. The recommendation to move to stage 2 and initiate the automation process for the most critical credits was in line with the organization’s interests.

The BIM experts expressed some concerns over how to proceed further and extend the results to the rest of the categories in the assessment. In their opinion, collecting information regarding the current workflows is very challenging. They suggested that the current assessment workflow and the tools used be documented so that can be used as the starting point for the development of technical infrastructure. This has been added as an addition to the preparatory tasks recommended before the implementation activities.

2. External feasibility: The interviewees pointed out that the external feasibility is dependent on the scale of the project and the stage at which BREEAM-NL team is involved in the project. They mentioned that in small scale projects not a lot of importance is given to BIM models and therefore, the models do not contain all the information required for assessments. The funding is also limited in such projects and therefore, any additional modeling efforts required on the part of designers would be met with resistance.

The experts liked the idea of providing recommendations on process and policy domains along with technological suggestions. They agreed that including the BIM requirements in BEP would be useful.

But in some of their projects, the BREEAM team is not involved at the project initiation. Therefore, in such projects adding requirements in the BEP would not be possible.

In general, the interviewees agreed that it is possible to get the necessary information for automated assessments from the external project stakeholders provided that the agreements could be made at the beginning of a project. Providing inputs for BREEAM-NL assessments and necessary documentation evidence is a part of their responsibilities. Providing more efficient ways of doing these assessments could also be beneficial to the external stakeholders. All the interviewees however mentioned that if the additional BIM requirements for these automated assessments involves a lot of extra effort from the design teams, it would be challenging to implement.

3. Usefulness in practice: The BREEAM team members perceived the usefulness of the research with regards to the concrete link it provides between BIM and each of the Energy and Material category credits. They expressed that the team is currently lacking an internal BIM champion and therefore they were unaware of the possibilities with regards to BIM-based assessments. They mentioned that for them, the expected time savings from automation is the biggest motivation for further follow up on the recommendations provided. They also mentioned that in the current way of working, the assessments are made at the end of each design phase and sometimes, it is too late to make changes. Therefore, the possibility of getting immediate feedback on designs is very beneficial for them.

The BIM manager of the organization expressed that while the BIM visions and ambitions are set out annually, implementation is lagging behind in general. This is mainly because the needs of the project teams are not always clear. So from the perspective of the BIM department, the output of this research bridges this gap to some extent and here lies the practical use for their work.

4. Potential risks: One remark made by the BIM experts is that the success of implementation depends on the quality of BIM models and there is a risk of obtaining incorrect results if the models are incomplete. However they agreed that the policy recommendations provided sufficiently addressed this issue.

7.4 Summary

This chapter summarized the results of the last phase of the research project i.e., evaluation of the proposed strategy. First, the validity of the results from the prototype was verified using one of the projects handled by the case study organization. It was found that the results produced by the Plug-in matched with the results from the manual assessment method. Following this, three BREEAM-NL experts and 2 BIM experts were presented the results of the research project and asked their opinion on the feasibility of implementation and usefulness in practice. The goal of this research step was to answer the last sub-question:

SQ 5: How does the proposed strategy help BREEAM-NL project teams?

The output of the research project gave the case study team a clear idea of the possibilities of BIM with regards to BREEAM-NL assessments and where they stand in terms of the level of BIM use. The usefulness of the implementation strategy and the recommendations proposed lies in the feasibility of implementation. The experts agreed that from an internal perspective, the recommendation to move to Stage 2 makes sense and is feasible with regards to the efforts that are required for this transition. From an external perspective, they felt that the recommendations provided address the issues of interdependency in information management, but implementation would require support from the client and adequate project budget. Overall, they expressed that proceeding with this implementation plan could make the BREEAM-NL assessment process more efficient and faster.

Chapter 8

Discussion & Conclusion

8.1 Answering the research questions

This research project started with an aim to aid the acceleration of BIM use for the purpose of green building assessments. After a preliminary literature review, it was identified that the current knowledge on this topic was lacking industry perspective. Although several scholarly works have been published in this subject in the last ten years, BIM-based green building assessments is not one of the commonly implemented BIM uses in practice. Therefore, it was decided to adopt design science research framework, which is a practice-oriented research strategy that responds to field problems faced by professionals. To arrive at the answer to the main research question, 5 sub-questions were formulated. The following sections will summarize the results of the thesis per each research sub-question.

SQ 1: Theoretically, how can BIM help in the assessment process of BREEAM-NL?

BIM can assist the designers and sustainability consultants involved in the BREEAM-NL assessment process through functionalities such as quantity take-offs, schedules and performance analyses. Some of the major challenges associated with the BREEAM-NL assessment process as expressed by the stakeholders interviewed are information management, design change management and manual compliance verification. BIM can help mitigate the first two challenges by fostering a model-based collaborative working process where stakeholders can get access to real-time information and data exchanges are standardized.

In response to the time and errors associated with manual assessments, BIM offers a possibility to automate the code compliance verification process. The possible level of automation depends upon the type of inputs required for assessments and how they relate to BIM software tools. Some credits such as the ones qualitative in nature or require contractual documents as proof of evidence cannot be automatically assessed. Whereas for credits that only require geometric information, assessments can be easily automated using BIM authoring tools. It was found that in Energy and Material categories of BREEAM-NL certification, assessments for 52 percent of the credit points can be fully automated, partially automated for 39 percent and cannot be automated at all for the rest 9 percent. To what extent these uses of BIM can be leveraged in practice depends upon the BIM Maturity stage of the project and the organization.

SQ 2: To what extent BIM is currently being used in BREEAM-NL assessment process?

The designers and BREEAM-NL experts involved in the construction process were interviewed to understand the current assessment workflow and the associated level of BIM use. It was found that currently, in the context of BREEAM-NL assessments, BIM models are not actively used. Information required for the calculations associated with BREEAM-NL credits are obtained primarily from 2D drawings. For most credits, the project team uses excel tools either made by them or provided by the DGBC for assessments.

Gathering the information required to determine the input parameters for the assessments is often the most challenging part. Although 3D models and 2D drawings are often shared in a Common Data Environment, the information is unorganized and therefore, email based communication is opted for information requests. Even in projects that aimed for higher BIM maturity stages, the BREEAM-NL experts were not involved in the BIM management activities such as formulation of BIM Execution Plan or data exchange guidelines. With regards to the automation of assessments, the stakeholders involved were not aware of the possibilities with BIM.

SQ 3: How does the industry situation compare to the promised potential of BIM for green building assessments? What are the reasons for the gap?

The status of BIM use for green building assessments as noticed in the case study organization is evidently lagging behind compared to the possibilities described in literature. Based on the literature review, for the credits in Energy and Material categories of BREEAM-NL, intelligent data gathering through quantity take-offs, scheduling, performance analyses and code compliance verification are the possible BIM uses for green building assessments. Whereas in practice, BIM models are primarily being used for design model reviews and in some cases, performance analyses.

The reasons for the gap between possible and actual level of BIM use for BREEAM-NL assessments are three-fold: 1) On the technological front, the lack of commercial software that can directly automate assessments and the poor interoperability between the BIM authoring and performance analysis tools are hindering BIM based GBA in practice. 2) At the BREEAM-NL team level, there is a lack of awareness about the possibilities of BIM and how to use them in practice. 3) At a project level, the dependency with the external stakeholders for inputs for assessments and aligning the information exchange formats with the requirements of the BIM based automation tools is challenging.

SQ 4: How can project teams start bridging this gap and make the best use of BIM for BREEAM-NL?

To increase the use of BIM for BREEAM-NL assessments, the project teams must be able to recognize the different levels of BIM use and where they currently stand. BIM Maturity models serve as useful means in this regard. By mapping the possibilities for BIM based GBA for each BIM stage, a maturity matrix has been developed. Based on this matrix, project teams or organizations can evaluate their current maturity stage.

Pre-BIM and Stage 1 BIM correspond to manual GBA methods since the technical infrastructure and collaborative practices between project teams are not evolved enough for automation at this stage. Stage 2 BIM allows the possibility for the automation of the assessment of the most critical credits through small to medium level changes in the process and policy domains accompanied by the development of associated technical infrastructure. At BIM Maturity Stage 3, automation of all the credits except for the ones related to performance analysis can be fully automated. This is because stage 3 represents an integrated way of working where all the project disciplines are involved from the beginning of a project and work together on a cloud based integrated BIM model. Therefore, all the information needed for BREEAM-NL assessments would already be available in the BIM models.

Between every two BIM stages, is a transition phase. For each transition phase, a set of recommended actions are provided that can be adopted in order to increase the maturity level of BIM implementation for BREEAM-NL assessments.

SQ 5: How does the proposed strategy help BREEAM-NL project teams?

To test how the proposed BIM implementation strategy can help BREEAM-NL teams in practice, the design strategy was demonstrated for the case study organization. Based on the interview results, the current BIM maturity stage of the BREEAM-NL team of the case study company was determined for each criterion of the maturity matrix. It was found that the overall BIM maturity of the team is at Stage

1. The action steps for moving towards Stage 2 BIM maturity and partially automated BREEAM-NL assessments were proposed. Considering the fact that the technical infrastructure for each credit has to be developed internally in the organization, it is recommended to aim for Stage 2 rather than Stage 3. The recommendations proposed were across three BIM fields: Technological recommendations regarding the development of automation tools, Process related recommendations regarding the definition of roles and responsibilities, BIM training and information management within the team, Policy related recommendations regarding additions to the BIM protocol, definition of stakeholder deliverables and requirements to be added in the BIM Execution Plans.

The proposed recommendations were presented to BIM and BREEAM-NL experts within the company to get their feedback on the feasibility of implementation and their value in practice. The interview results indicated that the incremental BIM implementation strategy proposed makes the recommendations more feasible. The interviewees expressed that 'going all-in' for BIM and aiming for Stage 3 maturity would be a very challenging transition and might not be worthwhile considering the ratio of efforts to benefits. Prioritizing the most critical credits alone for automation would already considerably reduce the assessment time, improve efficiency of the process and quality of results. The experts also expressed that having recommendations segregated per BIM field makes the implementation strategy more tangible and easy to follow.

And finally, to answer the main research question,

"How can the use of BIM for BREEAM-NL assessments be accelerated in practice?"

Based on literature and case study interviews, it can be concluded that the link between BIM and BREEAM-NL is not commonly known in practice. So the first step towards increasing the use of BIM for BREEAM-NL assessments would be to address this knowledge gap. When discussing the implementation aspects of BIM-based automated assessments, the following aspects must be considered: 1) The type of credit in question and its association with BIM tools 2) The different levels of BIM uses and their relationship with BIM Maturity 3) Amount of effort required to switch to a BIM-based assessment method and the consequent benefits that can be expected. The best suited BIM implementation strategy for a BREEAM team depends upon various factors such as their BIM maturity stage, the ambition and management support for BIM, degree of interest and investments in digitalization and lastly, the level of influence the team has in a given AEC project.

Using the BIM Maturity Matrix for BREEAM-NL assessments, project teams can identify their current level of BIM use. To move to higher maturity stages and towards BIM-based automated assessments, implementation actions must be taken across Technology, Process and Policy domains. A set of recommendations are proposed for each transition phase, which are generalizable for any BREEAM-NL team. However to determine which BIM stage is the most lucrative one for the team, and the finer details such as the kind of BIM software to be used for automation, further contextual analysis would be needed. For the case study team, based on their current maturity stage, BIM ambitions and organizational culture, it can be concluded that moving to partially automated BREEAM-NL assessments at BIM stage 2 would be highly beneficial. To reach this milestone, recommendations for BIM implementation have been proposed as shown in Figure 29.

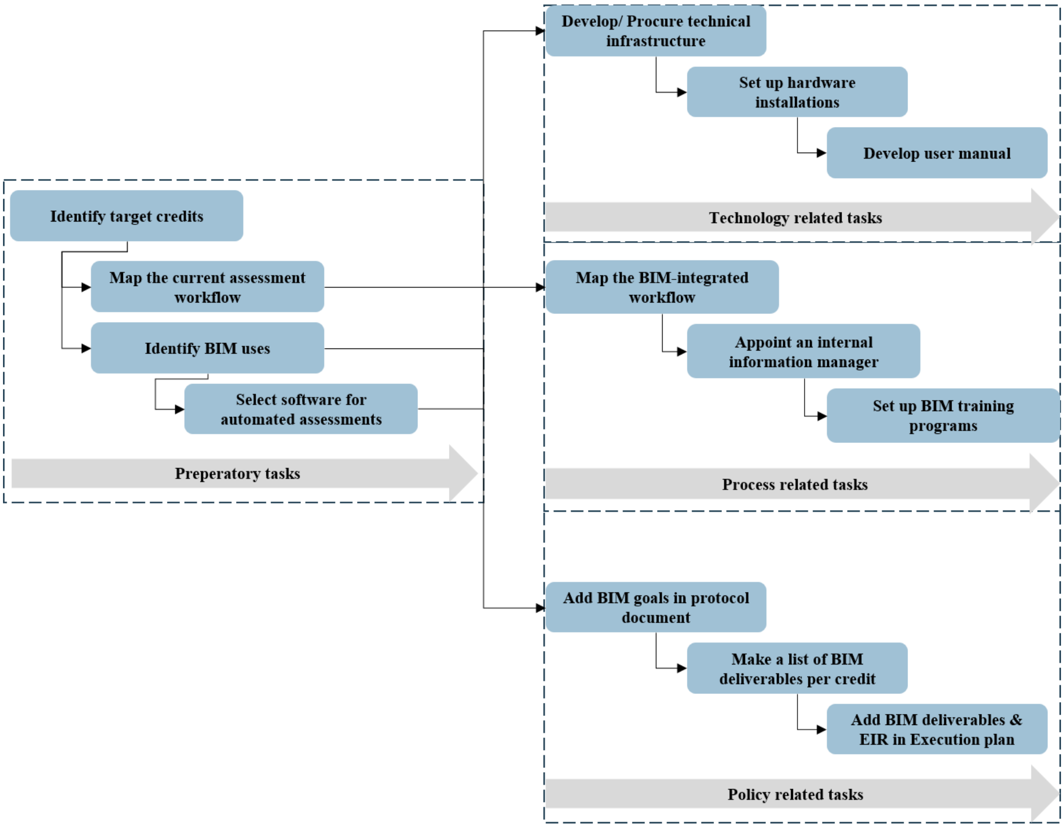


Figure 30 Final recommendations for the case study team (Own image)

8.2 Discussion

This research project approached the problem of BIM-based BREEAM-NL assessments from an implementation standpoint. As shown in Figure 31, earlier works on this topic focused heavily on technology, a few studies delved into the process related aspects. Some of the recent literature works such as Mohamed at al., (2018) and Alsehrawy at al., (2020) investigated the motivation factors for the adoption of BIM-based sustainability analyses and the challenges facing them. Until this point, the research has been from a theoretical standpoint and has not investigated the actual industry needs. This research project, done in collaboration with a Dutch consultancy, investigated the challenges associated with the assessment process of a national green certification scheme, BREEAM-NL.

Technological and people-related barriers to BIM implementation such as lack of software, interoperability issues, lack of awareness regarding the possibilities of BIM confirm the barriers discussed in the previous academic works. One group of barriers that were not discussed previously are the policy-related ones. The interview participants pointed out that the BREEAM-NL assessment tasks are carried out by the sustainability consultants but the information models are authored by the design teams. From the literature review it can also be observed that the contractual and protocol changes needed to accommodate the technological innovations of BIM-based GBA are currently not discussed. This will be an interesting research domain for future works. More recommendations for further research will be provided in Section 8.4.

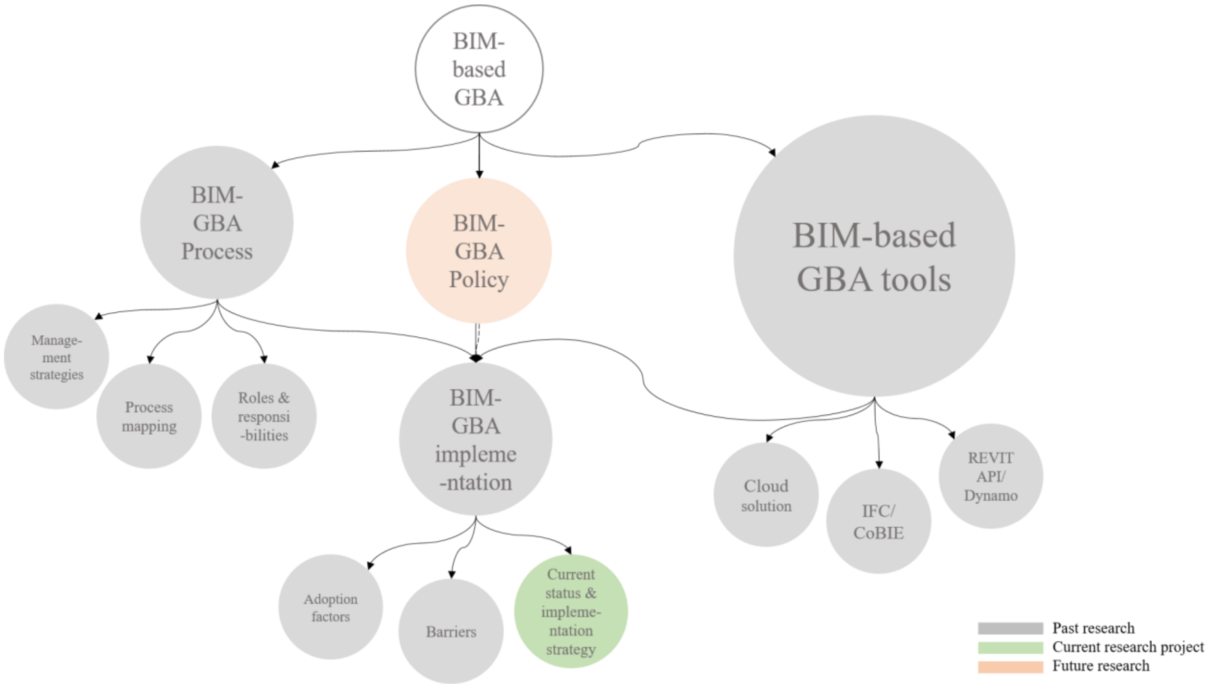


Figure 31 Positioning the research (Own analysis)

It was also observed that the maturity stage of a BREEAM-NL team has a strong influence on the possible level of automation. This is an expected conclusion as the starting point of the discussion for BIM-based green building assessments is the availability of quality information models. Therefore, the implementation of BIM-based assessments can be approached in incremental stages starting with the active use of BIM models for data gathering, followed by partial automation and eventually leading up to completely automated BIM-based assessments.

The primary contributions of this research lie in the following areas: 1) Investigating the actual status of BIM use for BREEAM-NL assessments in practice and discussing the needs of the industry 2) Integrating the topics of process and policy along with technology in the discussion of BIM-based GBA and lastly, 3) Providing a practical strategy to initiate the implementation of BIM-based BREEAM-NL assessments. However, like any research, there are some limitations to this study due to the boundaries drawn to the scope, number of case studies and interviews. These limitations will be discussed in the following section.

8.3 Limitations

The first limitation of this study is that only one BREEAM-NL project team could be studied in detail. This was due to the time constraints and also because the research project was carried out in collaboration with only one company. This project team was at BIM maturity stage 1. Therefore, the challenges identified in the BREEAM-NL assessment process and needs for improvement are coming from an early BIM adopter’s perspective. Ideally, 3-4 organizational case studies, each representing a different BIM Maturity stage must be studied to gain complete understanding of the challenges associated with BREEAM-NL assessment process and the role of BIM in addressing them.

The second limitation is that this research placed its primary focus on the design stage assessment and therefore, the actors interviewed were mainly involved in the design phases of a project. Although efforts were made to reach out to some contractors for interviews, this could not be accomplished. Inputs from

BREEAM-NL experts were instead used to understand the roles and responsibilities of contractors in the certification process.

Due to the limited time frame of the study, the proposed recommendations could not be tested in practice. Instead, expert interviews were used to validate the feasibility and usefulness of the proposal. These limitations must be considered while drawing conclusions from the research results. These points also serve as good starting points for further research on the topic of using BIM for green building assessments.

8.4 Recommendations for further research

So far in literature, little to no attention has been given to the implementation aspects of BIM-based green building assessments. This research aimed to address this gap by proposing a BIM implementation strategy to accelerate the use of BIM for sustainability analyses in practice. It is recommended to further investigate the impact of the proposed recommendations on the BREEAM-NL assessment process by doing an in-depth analysis of the pre-BIM and post-BIM scenarios.

The methodology adopted in this research must be replicated and extended to more case studies from different BIM maturity stages. This will provide a better understanding of the association between BREEAM-NL assessment challenges and BIM maturity. The results of such a study can help in quantifying the benefits that can be gained at each BIM stage with regards to green building assessments.

On the technological front, the automation tools discussed in literature are mostly single desk based. As the industry is moving towards cloud based integration, further work is needed to explore how real-time green building dashboards can be developed. Such an approach would better suit the multidisciplinary nature of green building assessments, where all stakeholders can actively monitor the status of compliance within their respective disciplines. Automated documentation has also been discussed for other GBAs such as LEED and BEAM plus. Whereas for BREEAM-NL, the nature of evidence to be submitted is flexible and the DGBC does not provide submittal templates for credits. This can be standardized to explore the possibility of automatically retrieving evidence based out of BIM models for a given project.

Of the three BIM fields, policy remains the least focussed one and probably the biggest barrier for implementation. Further research is required in this field to determine appropriate risk allocations and reward mechanisms for additional modeling effort required to implement BIM-based GBA tools.

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Appendix A

Non-exhaustive list of BIM uses

BIM use	Secondary use example	Brief description
Analyse	Analyse program requirements	Assessing design performance with regards to spatial requirements
	Analyse energy performance	Using BIM data to evaluate energy performance
	Analyse structural performance	Using BIM data to evaluate structural performance
	Analyse lighting performance	Using BIM data to evaluate lighting performance
	Coordinate design models	Compiling federated models to identify clashes
	Analyse sustainability performance	Evaluating the project performance against certification criteria
	Code compliance	Automated assessment of code compliance using model data and rules
Communicate	Review design models	Reviewing a model with stakeholders for validation and feedback
	Realistic visualization	Communicating discipline specific information through 3D renderings
	Draw construction documents	Developing necessary documentation for other stakeholders
Gather	Capture Existing conditions	Using sensor data to monitor the performance of facility systems
	Monitor maintenance	Monitoring the performance of the facility for maintenance planning
	Monitor assets	Monitoring the physical condition of the building assets
	Monitor space utilization	Tracking the use of the facility spaces for effective transition planning
	Quantity take-offs	Measuring the total amount or count of facility elements, materials etc
Generate	Author design model	Using BIM authoring tool to develop a design model
	Author cost estimate	Adding cost details of the building elements to facilitate estimation
	Author 4D model	Adding the time dimension to 3D models for effective planning
	Author construction site logistics model	Authoring a model of temporary and permanent elements on site across all phases for logistics planning
	Author temporary construction systems model	Designing and placing temporary systems in BIM models
	Compile record model	Using current information about the facility to update BIM model
Realise	Fabricate products	Use BIM data for the fabrication of building elements
	Layout construction work	Simulate the sequence for works for product assembly using BIM
	Automated control	Controlling on-site equipment operations through BIM

Appendix B

Elaboration on the assessment method for ENE & MAT credits

Credits	Sub-items	Assessment method	Assessment time	No. of revisions	Time per revision	Source
ENE 01	Energy efficiency	Step 1: Gather required information for EPC calculation from 2D drawings; Step 2: Calculate input parameters; Step 3: Manually enter inputs in ENORM/ Uniec software to calculate EPC value and percentage reduction compared to benchmark	Step 1: 1 day/ more Step 2: 2-4 hours Step 3: 1 hour; Total: 1.5 days/ more	8	1 hour if information about design changes is readily available	B5
ENE02	Sub-metering of energy consumption	Reviewing the design drawings and specifications of sub-meters to verify compliance	2 hours	4	2 hours	B1
ENE04	Energy efficient outdoor lighting	Reviewing lighting specifications and calculation of specific lighting per lux	2 days	4	2 days	B1
ENE05	Application of renewable energy	Step 1: Estimation of building energy demand; Step 2: Feasibility study of alternate energy sources and resulting carbon emissions	1.5 days	4	1.5 days	B6
ENE06	Minimising air filtration	Reviewing the design drawings and specifications of loading docks to verify compliance	1 day	1	NA	B1
ENE07	Energy efficient refrigeration and cold storage	Reviewing the design drawings and specifications of cold storage equipment to verify compliance	1 day	1	NA	B1
ENE08	Energy efficient elevators	Reviewing the design drawings and specifications of	1 day	1	NA	B1

		elevators to verify compliance				
ENE09	Energy efficient escalators	Reviewing the design drawings and specifications of escalators to verify compliance	1 day	1	NA	B1
MAT01	Environmental performance	Step 1: Extraction of material schedule from BIM model; step 2: Manual input of material details in the MPG calculation software	4 days	4	1 day	B4
MAT05	Substantiated origin of materials	First, the volume of each material used is determined along with the 'tier levels' of the materials based on their origin and BREEAM guideline. This information is fed into the MAT 5 calculator which is an excel sheet to get the final score	1 day	4	1/2 day	B4
MAT07	Robust design	First, the zones with high damage risk have to be determined and appropriate protection measures must be incorporated in the design	1/2 day	4	1/2 day	B4
MAT08	Building flexibility	Building flexibility Calculation tool has 13 questions to be filled in, in order to get a % value for flexibility. Depending on this value, a final credit score between 1-4 is possible	1/2 day	4	1/2 day	B4

Appendix C

Inventory of BIM-GBA integration approaches based on literature

For Type 1 credits:

S.no	Reference	GBA	Tool developed	Framework used	Proof of concept
1	Barnes & Castro-Lacouture (2009)	LEED	NA; Only new REVIT parameters	Input module: default and custom element properties in REVIT; Assessment module: REVIT plugin toolbar; Details of development method – NA	Applicability: 13 points & 1 perquisites; Proof: NA
2	Nguyen et al., 2010	LEED	NA; Only new REVIT parameters	Input module: default and custom parameters in REVIT; Assessment module: Conditional query feature using REVIT API; Interface between REVIT and MS Access	Case study; The basic idea is merely checking which of the credits are satisfied. A smarter version of the excel workbook.
3	Nguyen et al., 2016	LEED	REVIT add-in toolbar	Input module: REVIT shared parameters; data collection through REVIT API Rules & Assessment module: Algorithms developed on .NET platform	2 credits: green vehicles & access to quality transits
4	Wong & Kuan, 2014	BEAM plus	NA; REVIT parameters & material schedules	Input module: REVIT parameters; Assessment module: NA Documentation: data processing from REVIT schedules	26; Site Aspects, Material Aspects, Water Use, Energy Use and Indoor Air Quality.
5	Maroder & Ciaccio, 2021	LEED	Dynamo Script	Input: REVIT parameters; Assessment module: Dynamo	Indoor Water Reduction & consumption
6	Zhang et al., 2019	ESGBC	Autodesk Forge Application	Input Module: IFC data extracted from BIM 360; Green rating module: requirements encapsulated in SWRL rules Assessment module: Jess Reasoning Engine	

For Type 2 credits:

S.no	Reference	GBA	Tool developed	Framework used	Proof of concept
1	Azhar et al., 2011	LEED	NA; Demonstrated the use of IES-VE	Input Module: REVIT data exported in gbXML format Rules & Assessment Module: IES-VE	6 credits &16 LEED points; Topics: Water use, energy, thermal comfort & daylight
2	Wu & Issa, 2012	LEED	Demonstrated the use of web services like Lorax Pro in combination with AECOsim	Input Module: AECOsim Energy simulator Assessment module: LEED API & Lorax Pro	LEED EEAP2: Energy Performance
3	Cheng & Das, 2014	EMSD energy code	BIM-based web service protorype	Input: gbXML file Energy simulation: Energyplus Assessment: Jess rule engine	EMSD building code for daylighting, Hong Kong
4	(Salgueiro & Ferries, 2015)	LEED & BREEAM	NA; Framework for using ArchiWizard and Excel together with REVIT	Input: REVIT data exported to gbXML through ArchiWizard Assessment module: Not reported	NA
5	Liu et al., 2020	Green Mark	Cloud based Green Mark platform	Input: IFC model; Analysis & assessment: Greenmark cloud platform; details of development NA	NRB1-1 of GreenMark

For Type 3 credits:

S.no	Reference	GBA	Tool developed	Framework used	Proof of concept
1	Ilhan & Yaman, 2016	BREEAM	GBAT desktop application	BIM data: IFC file with custom property sets External database: Green Materials database developed from BREEAM requirements Assessment module: GBAT desktop application	MAT- All categories
2	Bergonzoni et al (2016)	LEED	Dynamo Script	BIM data: REVIT parameters; External database: ASHRAE spreadsheet; Assessment module: Dynamo script	IEQ P1 and IEQ C2

3	Chen & Choung, 2017	LEED	REVIT Plugin	BIM data: default REVIT parameters External database: Web Map Services to retrieve maps Assessment module: LEED rules algorithm	SSc2 SS4.1
4	Jalaei and Jrade, 2014	LEED	REVIT plugin for gbXML export	Input Module: Created REVIT material families using information in external green material database; Assessment module: Unclear	NA
5	Chen & Nguyen, 2019	LEED	REVIT Plugin	Input: Material information from REVIT; Web Map Services for transport information; Plug-in developed using REVIT and WMS API	MRc5
6	Li et al., 2019	LEED	Dynamo Script	Input: Project location- manual input/ REVIT parameter & surrounding amenities extracted from WMS Assessment: Dynamo script verifies the presence of amenities within 500m	LTc4, LTc5

Appendix D

Summary of Interview questions

Interviewee name	Role	Experience
B1	BREEAM & LEED Expert	3 years' with LEED projects; 2+ years in BREEAM
B2	BREEAM & LEED Expert	5+ years' experience with LEED & BREEAM
B3	Project manager; Certifications and energy transition	20+ years in Building Physics & Energy team; 13+ years in BREEAM-NL projects
B4	BREEAM & WELL Expert; Circular economy advisor	2.5 years' experience with BREEAM & WELL; Primary focus on Materials
B5	Energy specialist	5 years' experience with the organization as Energy specialist
B6	Energy specialist	2 years' experience with the organization as Energy specialist
B7	Architect	20 years' experience in the industry; Started as a junior architect, currently a project leader.
B8	MEP designer	30 years' experience in the organization; Started as MEP draftsman, currently an MEP designer
B9	MEP designer	12 years' experience in the organization; Started as a MEP designer, currently the project lead for MEP
B10	BIM Manager	9 years' experience in the organization; Started as BIM coordinator, now a BIM Manager
B11	BIM & Digitalisation leader	Overall 15 years' experience; Starting from architect, , to product manager to digitalization leader
B12	Automation expert	9 years' experience in the industry; Currently working as the business manager for a process automation company

Interview questions

BREEAM-NL Experts

After gathering the general information about the interviewee's role and experience in the industry, the following general set of questions were posed to the BREEAM team members:

Process Management:

1. How are you introduced to a new project?
2. How would you describe the general BREEAM certification process?
3. Is this process common for all the projects?
4. How would you describe the role of Deerns/ BREEAM experts in this process?
5. At what stage of the design are you generally introduced to a project?
6. When are the sustainability & BREEAM ambitions decided?

Information exchanges:

1. What are the information exchanges with different stakeholders?
2. What is the format of information delivery?
3. Are the deliverables and information exchange standards agreed upon at the beginning of a project? If not, is the current process without specification of deliverables & responsibilities efficient?

4. What kind of document management system do you use?

Connection to BIM:

1. To what extent is BIM currently used in the certification process?
2. Do you see BIM as a potential tool for improving the current process?
3. What are the challenges you encounter while using BIM?
4. Do you discuss these challenges with the BIM team?

Collaboration with external stakeholders:

1. How would you describe you association with the external stakeholders?
2. What is the medium of communication?
3. What are some of the major challenges in collaboration and communication?

Challenges and pain-points:

1. In your opinion, what are some of the inefficiencies tasks in the current process?
2. What are the common errors you notice?

BIM & digitalization experts

After gathering the general information about the interviewee's role and experience in the industry, the following general set of questions were posed to the BREEAM team members:

BIM Department functions:

1. What is the role of BIM team in the organization
2. What constitutes a typical BIM execution plan?
3. How do you manage teams across different disciplines in BIM projects? What are the interfaces with other teams?
4. From the organizational perspective, what are the main drivers for using BIM?

BIM Modeling:

1. Do you follow any BIM development protocols?
2. Do you have information delivery standards? What do they constitute and how do they relate to national standards?
3. What are some of the common challenges you've had to deal with when you received models from external teams?
4. In your opinion, how can information retrieval be enhanced? Are standards helpful, and to what extent?

BIM Limitations

1. What are some of the drawbacks of BIM-based processes?
2. Does having information rich models come with complications? What are they?
3. What stage of BIM maturity do you place Deerns in? What are the technical barriers?

BIM & People

1. What is the level of acceptance towards novel BIM processes? Is there any resistance?
2. If yes, what are the reasons?
3. Does working with BIM improve collaboration and information management between teams?
4. How are design changes managed?
5. To what extent do you use real-time collaborative platforms?

Designers (MEP & Architect)

After gathering the general information about the interviewee's role and experience in the industry, the following general set of questions were posed to the design team members

Process:

1. How are you introduced to the BREEAM requirements in a project?
2. What are the credits you deal with in ENE & MAT categories?
3. Are you already aware of what the BREEAM requirements are?
4. At what stage of the design do you start considering these requirements?

Information exchanges:

1. What are the information exchanges with different stakeholders?
2. What is the format of information delivery?
3. Are the deliverables and information exchange standards agreed upon at the beginning of a project? If not, is the current process without specification of deliverables & responsibilities efficient?
4. What kind of document management system do you use?

Connection to BIM:

1. To what extent is BIM currently used in the certification process?
2. Do you see BIM as a potential tool for improving the current process?
3. What are the challenges you encounter while using BIM?
4. Do you discuss these challenges with the BIM team?

Collaboration with external stakeholders:

1. How would you describe you association with the external stakeholders?
2. What is the medium of communication?
3. What are some of the major challenges in collaboration and communication?

Challenges and pain-points:

1. In your opinion, what are some of the inefficiencies tasks in the current process?
2. What are the common errors you notice?

Appendix E

Interview results

Interviewee B1 – BREEAM & LEED Expert

- 3 years' experience with LEED certification projects in Colombia
- Joined the organisation two years ago, has worked with BREEAM ever since

There is no documented project management plan or official briefing session for BREEAM projects. The company is usually involved after the preliminary design stage. The first step is to conduct a feasibility study based on client's ambitions and the preliminary design to obtain an overview of credits that can be targeted to achieve the client's ambitions. This is done in Excel as a scorecard. Then the design proceeds to further stages and we check the design compliance with BREEAM requirements as it evolves. BREEAM assessor is contacted at the beginning of definitive design phase and the interim assessment happens at the end of definitive design phase.

Before the construction begins, a contractor agreement is drafted involved to ensure compliance with the requirements selected credits. It includes a list of deliverables. The final step is to collect the as-built information, verify it and submit it to the assessor for final rating.

The BREEAM Scorecard is not shared with external stakeholders, but they're informed of the ambitions, targets and what their designs have to comply with. Currently, the deliverables from each party are not clearly defined or agreed upon during project initiation. But doing so, will help make the process more efficient.

The design information is exchanged through 3D Models and 2D drawings. For Innocent project, BIM 360 is used as the data sharing platform. But the issue management feature is not currently used by the BREEAM team. The communication with external stakeholders is mainly via emails.

Manual compliance verification and change management are the critical points. Gathering the required information from stakeholders is also time consuming. BIM is being used as a dumping tool, from which BREEAM team has to filter the relevant information. That needs to be changed. Deliverables and responsibilities have to be clearly agreed upon.

Interviewee B2: BREEAM & LEED Expert

- 5 years' experience in the organisation with LEED & BREEAM
- Currently takes the role of project manager in certification projects

A typical BREEAM project involves these steps:

1. Quick Scan to identify the credits to be targeted,
2. Kick-off meeting to communicate the plan to other stakeholders
3. Verifying design compliance – an iterative process that continues until the end of detail design phase
4. Obtaining interim rating – Although this is optional, we often do it to avoid the risk of non-compliance at the end of construction
5. Specifying contractor deliverables – through a document and a similar kick-off meeting as in the design phase
6. Reviewing as-built documents, submitting the evidence and obtaining the final rating.

The main responsibility of BREEAM experts is to provide a strategy for meeting the client's ambitions and obtaining the envisioned rating, check if the designs comply with the BREEAM requirements and if yes, gather the required evidence to submit it to the assessor.

Information is mostly delivered through 2D drawings obtained from individual 3D models currently. Information requirements are not standardised as of now. Most of the evidence required for BREEAM is usually already a part of design documentation, so the information is already there. It's only a matter of collecting it from the right people at the right time. At the end of every design phase, stakeholders deliver a bunch of information to the BREEAM team to sort through it for the relevant information. This is something that the team is trying to change by defining the deliverables early on.

A clear connection between BREEAM and BIM is unknown to the team as of now. It has to be established and pilot projects should be started. The BE team does not get enough attention for such initiatives as this is a very small part of the business for Deerns. The team would be open to BIM oriented processes if that makes the job easier, provided they get some preliminary knowledge on using these technologies and get started on actually doing it.

Change management and responsibility division are the main issues when it comes to collaboration with external stakeholders. The team doesn't have access to the latest version of their BIM models in all cases. And sometimes, the changes are notified too late in the process.

Interviewee B3: Project Manager; Energy transition & certification projects

- 20 years' experience in the organisation
- 13 years' experience with BREEAM-NL

A typical BREEAM project starts with the client ambition that forms the basis for feasibility study. After that, the design teams progress with their designs and the BREEAM team verifies the compliance with BREEAM requirements at the end of every design phase. After the technical design is ready, design assessment is done to get the interim rating. Once the construction starts, the contractors are responsible for making sure that the building complies with the BREEAM requirements. BREEAM team merely does the quality check of the submitted documents, complies them and submits to the assessor.

Ideally there must be a standard, documented project plan but currently, it is not there. Compiling the documents for assessments is very time consuming. BREEAM integration with the design team can be improved. The problem with the current system is that the design is made by one stakeholder and verification is being done by someone else. If the designer isn't aware of and clearly understands BREEAM requirements, they can't ensure its compliance. Designers are not able to assess the compliance of their designs themselves. If BIM can facilitate the verification of design compliance in a smarter way, it would save a lot of time.

Responsibility division is the main challenge. Currently, the administrative tasks take up about 70% of the time in these certification projects and only 30% goes into providing sustainability advice to the client. This should be the other way around. Ideally more time has to be spent on the front end preparation of BREEAM-NL projects i.e., we as BREEAM experts must first educate the rest of the project partners about the certification requirements and individual responsibilities to meet those. This would reduce the time spent on administrative tasks in the later phases of the project.

Currently BIM is not being used actively in the assessment process. All the design teams have their own BIM models that is used to generate 2D documentation. These BIM models are therefore only used as the source of information for assessment as well as for providing proof in the documentation stage. The assessments are not automated. There are also pitfalls of automation such as project partners not knowing the logic behind the requirements anymore. Automation can be used to inform the project teams of (non-)compliance and speed up the assessment process, but at the end designers must be responsible for fulfilling the requirements.

Sometimes the benefits of advanced BIM applications are not clearly known. For example, we are witnessing an increase in uptake in BIM360. But I do not see a difference between BIM360 and a drop box or SharePoint. So it is important to match the advantages of BIM with BREEAM-NL requirements, challenges faced and ambitions of the team to provide motivation for the transition.

Interviewee B4: BREEAM & WELL Expert

- 2.5 years' experience in the organisation
- Advisor for material circularity

This interview mainly focussed on the assessment process of material category credits.

I am a BREEAM and WELL AP, but I mostly work on sustainable materials and circular economy. The stakeholders I deal with mostly are Architects and the construction manager. We currently store all the information in the BIM Model and import the IFC file in Solibri to get quantity take offs. The information about the material name and volumes is present in the BIM models. But information about the type of sourcing/ quality is not present in the models. Sometimes there are thousands of materials added in the BIM file and I have to segregate it by building part and aggregate the same materials by hand. It would be easier if we standardized the working and documentation methods. Manual calculation is very time consuming and if we can do it in a more automatic way, it saves a lot of time. And it would give me more time to advise the stakeholders on sustainability and design optimization.

For MPG calculations, we used to use MPG Calc, but it is not very efficient as it is not linked to National Material Database. But there are better tools now such as OneClick LCA, which we are currently exploring. OneClick LCA can be linked to BIM models as well, so data extraction is faster.

For credits such as detachability, we ask the architect to provide us evidence on how it has been accomplished. Strictly speaking, it is the responsibility of design teams to provide compliance evidence and the role of BREEAM expert is to provide advice on how it can be improved. In the current way of working, most of our time is spent on administrative tasks. It is also due to the budget and time constraints. Design teams do not spend so much time on detailing the BIM models any more than bare minimum. The more information we store in the BIM Models, the slower the program is going to run. So that is also a trade-off that must be considered.

Interviewee B5: Energy specialist

- 5 years' experience in the organisation
- Role in BREEAM-NL projects mostly limited to ENE01 credit

This interview mainly focussed on the assessment process of ENE05

ENE 05 assessment involves two main steps: Estimating the energy demand of the building and studying the feasibility of alternate energy sources and the resulting CO_2 emissions. Both steps can either be done in an excel sheet or a dynamic energy modeling software.

Dynamic simulations would require an export ready BIM model, which is usually not the case. So to opt this approach, the team would have to build an energy model from scratch which could take weeks depending upon the scale of the project. Once the model is ready, simulations and results can be obtained within half a day from software programs such as IES-VE. The other option is to clean up the BIM models and make necessary adjustments to run the simulations. This cleaning up process would take about one day.

In the manual method ie., using excel, it takes a total of 2.5 days for both steps combined. This is not including the time taken for collecting the information. This is a seemingly easier approach, especially for senior colleagues, who are not particularly interested in or support the change to BIM based workflow. Therefore in the organization, there are islands of excel sheets for each calculation whereas it could all be integrated with one BIM model.

The information already available in the design models must be leveraged in an appropriate way. Protocols or execution plans must include the considerations for energy analysis, to avoid re-work and promote efficient use of information.

Interviewee B6: Energy specialist

- 2 years' experience in the organisation
- Role in BREEAM-NL projects mostly limited to ENE05 credit

This interview mainly focussed on the assessment process of ENE01

ENE 01 assessment process involves three main steps: Gathering the required information either from 2D drawings or asking for missing information from stakeholders by e-mail; Calculating input parameters for the EPC calculation and entering these values in UNIEC or ENORM software for EPC calculations (BENG in the new versions of BREEAM-NL)

The input parameters include geometric information such as surface areas, length of the water pipe; installation details such as devices used, type of distribution etc. Energy systems and lighting fixture details, etc.

Gathering the required information takes up most of the time, ranging from a day to weeks depending upon how well the project teams collaborate. Once that information is available, calculating the input parameters takes about 4 hours depending on the size and complexity of the project of course, and the calculation in ENORM itself takes only an hour.

Ideally, this calculation must be done once at the end of every design stage, so about 4 times per project. But on an average around 8 revisions can be expected per project due to major design changes. In some projects, it was even 20! For each revision, the calculation takes up only an hour, but getting the right information again is a challenge. So, I would say communication is the biggest challenge in the process.

All the input data can be stored in BIM models, but currently the models are not to that level of detail. Plus I personally am not aware of BIM uses and applications so I prefer ENORM. If using BIM can improve the process and save time, the change would be very welcome of course.

Interviewee B7: Project leader, Architect team

- 20 years' experience in the industry; Started as a junior architect and currently leads the projects
- Experience with BREEAM-NL: Formal training in BREEAM-NL; most experience with office projects

The role of the architect in the projects with BREEAM-NL ambition is to make sure that the architectural design fulfils the certification requirements. In most of the projects in the recent times, the BREEAM-NL ambition at the beginning of the preliminary design. In the early stages of the preliminary design, the BREEAM-NL strategy i.e., the credit list is shared with the other project teams.

The credits that need inputs/ actions from multiple actors are more challenging. It's a dynamic negotiation process. The role of the BREEAM-NL expert is governing the progress of certification work and coordinate with all the stakeholders. At the end of design phases, we do a rough calculation to check if BREEAM-NL requirements are satisfied.

Experience with BIM is not extensive, but I have used it for 3D modeling purposes. In order to reap the higher benefits such as automating some processing using BIM, guidelines for modeling also have to be set up at the beginning of the design phases. It also requires additional time in modeling and therefore financial compensations have to be put in place.

Overlap of responsibilities in multidisciplinary credits are the biggest challenges. Some organizational strategies are needed to clearly demarcate the roles and responsibilities and determine a joint strategy for delivering a certified building.

Interviewee B8: MEP project manager

- 12 years' experience in the organisation
- Roles taken: MEP designer & MEP project manager

I'm a Project manager in the MEP team. I have been working with Deerns for 12 years. Started as an MEP designer. As a project manager, I was responsible for the deliverables from MEP team for BREEAM in about 5-6 projects. Not a BREEAM-NL specialist, but my role is about coordinating the BREEAM requirements within my team and facilitating the acquisition of certificates. Collaborative role – between MEP team and BREEAM team and external stakeholders.

BREEAM process always starts with client's ambitions, based on which the BREEAM specialist, in consultation with the project managers from design teams makes a strategy/ list of credits that the project can aim for. Energy credits are relevant for MEP; it is not just for BREEAM but also for other building regulations. As a project manager, I am aware of the general BREEAM requirements and convey it to my team and ensure that everyone knows their responsibilities and deliverables. Easiest credits to work on in these certifications are the ones that can be worked within the team. Credits that require inputs from different teams are always more challenging and involve an iterative process of design and verification.

The information required to calculate BREEAM points is mostly about building geometry and theoretically be stored in BIM models. But it is not a linear process. There are several revisions and optimizations as we progress from concept design to project execution. Also, knowledge about BIM with relation to BREEAM is not yet known. When we started with BREEAM projects the calculations were made using prints of 2D drawings using a calculator. But technology has evolved so much in the past decade, that it is now possible to do these tasks more efficiently. But people doing these tasks should also evolve in parallel to technology, and that's where we are lagging behind. The tools are there but we are not getting any younger! The older generation needs demonstrations and knowledge sharing sessions to know how these digital systems work and how we can benefit from them. On the technology front, we are also not there yet completely; There is no single tool for all your needs and the transfer of data between applications is always challenging.

There is the question of the level of detail in BIM models. We do not usually add minor technical details such as elevator models. We make sure that it is compatible with the space allotment provided by architect and then provide technical specifications in the form of RFPs provided to the contractors.

Communication with external stakeholders is mostly by email at this point. But lately we have been switching to platforms like BIM 360. In such projects you always have access to the most latest version of BIM models. This saves a lot of rework arising out of miscommunication or using wrong information. There is also quite some difference between as-built design and the design drawings that were used to make calculations. BREEAM has a post-construction review but the minor details are not always verified. Ideally, the best digital intervention in the BREEAM process would be to have a real-time BIM dashboard that takes input from the most recent BIM models and provides an indication of the resulting BREEAM compliance status.

Interviewee B10: BIM Manager

- 9 years' experience in the organisation
- 3 years' experience as BIM Manager

As a BIM manager, the main activities are to set annual BIM goals, and make execution plans and help people with the transition. A typical BIM plan would include general BIM goals in terms of what technologies to adopt, target teams for the transition, implementation plans and individual team roles for the same. It also includes plans for knowledge sharing as well as customised automated workflows.

The main driver for BIM is because the clients ask for it. Improved collaboration is another reason. Construction projects undergo a lot of design changes, and having real-time updated information is very valuable to the other stakeholders. Issue management also makes design coordination easier. It is also time saving.

Ideally, there must be one BIM coordinator per each team that has knowledge of BIM capabilities, best practices and implementation strategies. But a lot of project managers don't add BIM coordinators to the projects. In many cases, the BIM team does not have the knowledge of the current workflow and therefore cannot propose strategies for improvements

A BIM protocol is a part of the contract with the client. Together with the designers and engineers, more specific agreements are made on how to fulfil the protocols, individual responsibilities, information exchange points and mode of exchange, level of detail, file naming rules, communication and collaboration rules etc. But this agreement is not a part of the contract.

National standards are followed as much as possible, but they're helpful only to a certain extent. The standards and object libraries do not cover all the requirements yet. It is going to take a couple of years until its really useful. In the meanwhile, project teams must make agreements with each other on how to deliver information for each project, as well has be more open about exchanging information. The process must be more transparent and collaborative.

Successful BIM implementation requires detailed execution plans and the initiative and commitment of the project managers to switch to BIM-based workflows. People often consider BIM as a time-consuming intervention. What they don't realize is that the time-savings that come with BIM adoption in the later stages of projects outweigh the additional time spent in the beginning of a project.

Interviewee B11: Digitalization Leader

- 15 years' experience in the industry

- 5 months experience in the organisation

Two main focusses for BIM adoption this year: Information modeling with REVIT and development of custom automation tools. The main challenge of the latter is that it is heavily dependent on the quality of BIM models shared by other stakeholders. So getting the right information is the first step.

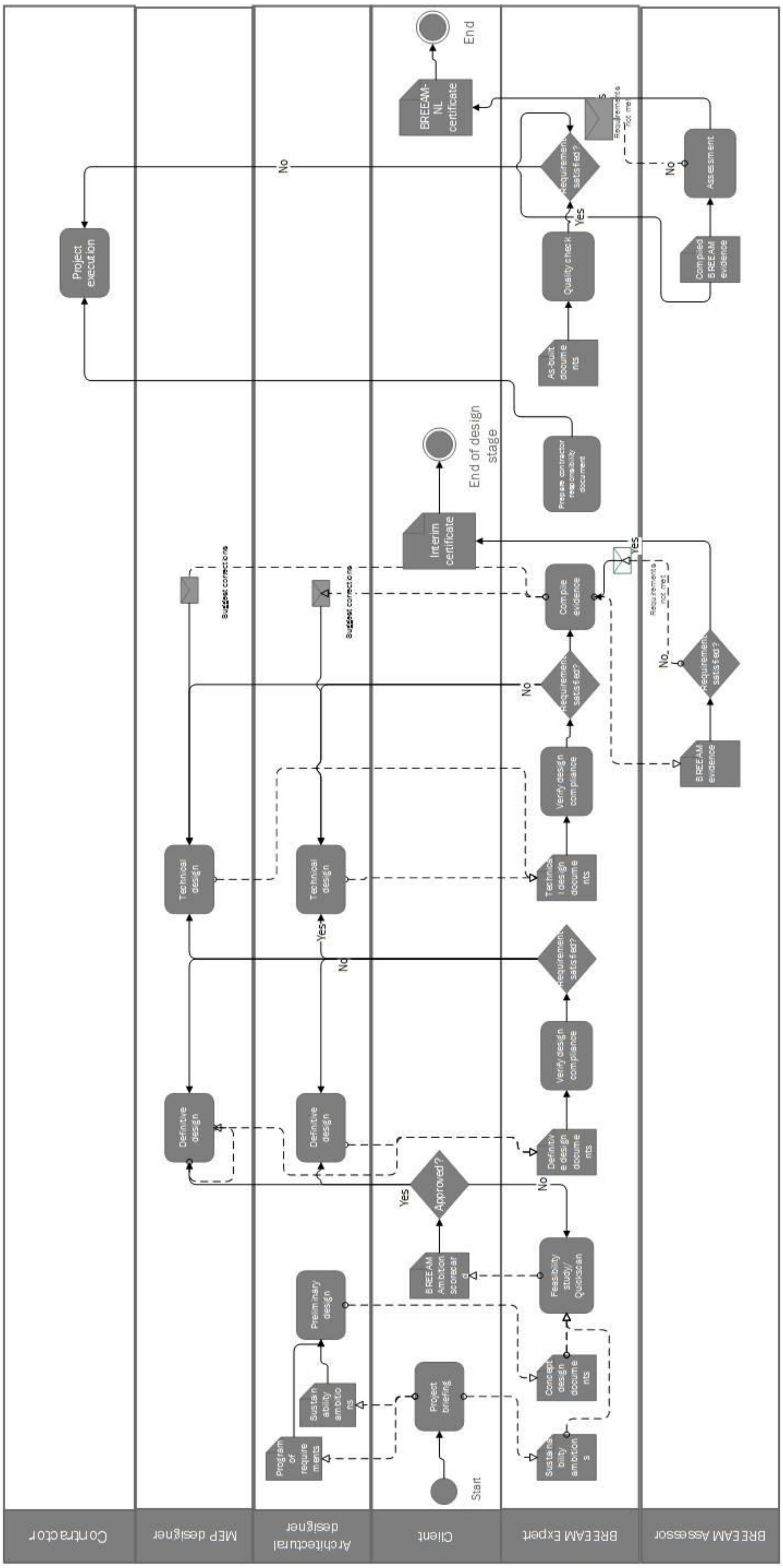
For collaboration and document management, BIM 360 is a promising tool. Autodesk Forge allows for the development of custom tools on top of BIM 360, and that makes it even more powerful. IFC support of Autodesk is not great. In Europe, there's some resistance for proprietary formats and open standards are preferred. BIM Collab is an equivalent alternative for BIM 360 in this regard.

Implementation is always challenging when it comes to BIM. Technology and process must evolve in parallel. Without either one of it, any new solution will be useless. People are used to working in a certain way, and are hesitant to change. So solutions must be simple for a successful implementation.

Moreover, information requirements must be clearly defined. Standards are helpful to some level, but they are not fully developed and therefore can't cover all the information requirements. For the rest, project based agreements can be made on how to deliver that information.

Appendix F

BREEAM-NL assessment process mapping



Appendix G

BIM Maturity Matrix for BREEAM-NL assessments

BIM Stage		Pre-BIM	Manual	Partial automation	High automation
BIM Field	**Sub-domain**				
Technology	Model content (T1)	2D line drawings representing 3D geometry are shared	Simple 3D Models are shared but only for visualization purposes	Detailed 3D models including all design stage details such as costs, quantities of materials etc	3D Models consisting of both design & construction details
	Hardware support (T2)	NR	Limited hardware to support BIM tools; Actions requiring heavy processing power are hard to execute	Sufficient hardware support across the entire team; Replacements and upgrades are well planned	Additional investment in powerful hardware systems to improve BIM productivity
	Software tools (T3)	No software tools used to automate the assessment process	Few commercial tools mandated by DGBC for the assessment of certain credits are used; For the rest, excel based calculations are common	Customized automation tools developed for the assessment of Type 1 & 3 credits that take the highest amount of effort	Technical infrastructure for automating the assessment of all Type 1 & 3 credits available; Semi-automated workflow for Type 2
Process	Information exchange (Pr1)	2D CAD drawings stored in individual systems and exchanged in a paper format	A combination of 2D & 3D electronic files shared through emails	Coordinated discipline specific 3D models shared on a Common data environment	Integrated, interoperable 3D models managed in a cloud based BIM environment
	Management support for BIM (Pr2)	NR	Starts to see the potential use of BIM and BIM vision for BREEAM-NL projects is developed	Small scale pilot projects developed to test the effectiveness of the BIM integrated workflow	Support and commitment of resources for large scale BIM implementation
	BIM Training (Pr3)	NR	BIM is not actively used in the process so training is provided on an ad-hoc manner, only when it is required	Extensive BIM training provided by the information manager to target personnel that have the most interaction with BIM activities	General BIM awareness training programs established for the entire team
	BIM roles (Pr4)	NR	BIM is not yet an integral part of the process; therefore defined BIM roles don’t exist	An information manager is appointed within the team responsible for BEP agreements, and data management	BIM becomes an integral part of the assessment process and therefore, internal BIM roles are defined within the team

				for automated assessments	
Policy	BEP (Po1)	None	BEP for a project exists but BREEAM-NL team is not involved in its formulation	Basic specifications required for the automation of assessment is included in the BEP	Detailed BIM requirements for Type 1 & 3 credits; MVD for Type 2 credits are included in the project's BEP
	Contractual (Po2)	Not relevant for BIM	BREEAM Expert team does not have involvement in the formulation of the BIM protocol	BIM protocol for the project is formulated which includes the requirements and deliverables of BREEAM-NL team	Reward mechanisms are introduced in the contracts to compensate for the additional BIM effort required from all parties
	Deliverables (Po3)	None	BREEAM-NL deliverables are divided per credit per stakeholder but are not BIM specific	BIM deliverables for BREEAM-NL assessments for selected pilot credits are specified	BIM deliverables for all BREEAM-NL credits are specified

Appendix H- Software selection

The demonstrated BIM-GBA integration approaches in the literature are used as an inventory to score the possible solution approaches. Based on the interview results, 5 criteria important for a successful BIM adoption have been identified: Ease of use, reliability of the tool, compatibility with different exchange formats, facilitation of collaboration and scalability of the tool. The solution approaches taken from literature are scored against these criteria. The available set of solutions varied for each type of credit, so the multi-criteria analysis is made separately for each type.

Table H1 – MCA of solution approaches from literature for Type 1 credits

Criteria	Weight	% Weight	REVIT+ Excel	REVIT+MS Access	REVIT plug-in	REVIT+ Dynamo	IFC+Cloud application
Ease of use	10	28%	90	70	100	90	0
Reliability	8	22%	100	90	100	0	50
Compatability	8	22%	50	50	50	0	100
Collaboration	7	19%	0	0	0	0	100
Scalability	3	8%	0	0	50	0	100
	36		58	51	**65**	25	**61**

Table H2 – MCA of solution approaches from literature for Type 2 credits

Criteria	Weight	% Weight	REVIT Plugin	REVIT + BPA software	Cloud platform
Ease of use	10	28%	100	0	50
Reliability	8	22%	100	50	0
Compatability	8	22%	50	50	100
Collaboration	7	19%	0	0	100
Scalability	3	8%	0	0	50
			61	22	60

Table H3 – MCA of solution approaches from literature for Type 3 credits

Criteria	Weight	% Weight	REVIT+ Dynamo	REVIT plug-in	IFC+ Desktop app	IFC+Cloud application
Ease of use	10	28%	50	100	0	0
Reliability	8	22%	0	100	50	50
Compatibility	8	22%	0	50	100	100
Collaboration	7	19%	0	0	0	100
Scalability	3	8%	0	50	100	100
Final Score			14	**65**	42	61

As seen in Tables H1, H2 and H3, REVIT based plugin scored the best, followed closely by a cloud based application. It must be noted that these results are specific to the context of the case study team, and the results can vary for a different team based on their subjective preferences for the defined criteria.

Appendix I

MAT5 Plug-in development details

H.1 Input requirements for MAT5 Calculation

The aim of MAT5 credit is to encourage the use of materials with a responsible and sustainable origin in the main building parts of a project. The main building parts for this credit are defined and named as shown below in Table H1. An excel based calculator tool is provided by the DGBC to assess the number of credits achievable by a project. For this calculation, the following inputs are required:

1) List of all applicable materials and their volumes in each building part
2) Their *Tier levels* based on the kind of sourcing of the raw material
3) Percentage of material volume for which tier levels are known.

Table H1 List of elements applicable for MAT5 calculation

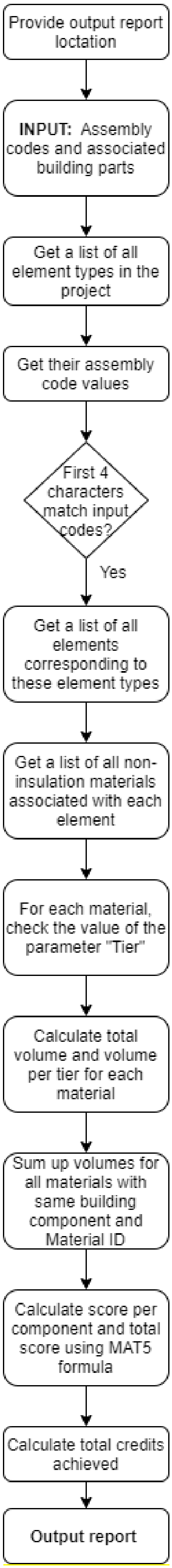
Main building section	Subdivision	Nl-SfB Elements
A	Foundation construction	16.01 Foundation beams
		16.02 Foundation feet
		17.01 Foundation piles
	Substructure general	16.03 Cellar walls
		16.04 Upright brickwork
B	Internal walls	22.01 System walls, non-load-bearing
		22.02 Systematic walls, non-load-bearing, movable
		22.03 Solid walls, non-load bearing
	Internal wall opening	32.01 Internal frames
		32.02 Inner doors
		32.03 Internal glazing
C	Exterior walls	21.01 Cavity walls, inner leaf
		21.02 System walls
		21.03 Curtain walls
		21.04 Elemental facades
		41.01 Cavity walls, external leaf
		41.02 Coverings
		41.03 Finishing coats
	Outer wall openings	31.01 Adjustment frames
		31.02 Exterior window frames
		31.03 Exterior windows
		31.04 Exterior doors
		31.05 Transport doors
		31.07 External glazing
		31.08 Tight filling
D	Roofs	27.01 Flat roofs
		27.02 Pitched roofs
		47.01 Coatings, exterior
		47.04 Flat roofing materials
		47.05 Pitched roofing materials
	Roof openings	37.01 Skylights
		37.02 Skylights
		37.03 Skylights

Main building section	Subdivision	Nl-SfB Elements
E	Main load-bearing structures	28.01 Solid walls, load bearing
		28.02 Girders + beams
		28.03 Consoles
		28.04 Lintels
		28.05 Columns
		28.06 Constructions
		28.07 System walls, load-bearing
F	Floors	23.01 Floors with cantilever
		23.02 Balcony and gallery floors

H.2 Plug-in development

Table H2 Mapping MAT5 element codes with NL-Sfb coding system

Building Part	MAT5 element coding system	NL-Sfb/ STABU coding system
A	16.01 16.02	**16.1**X.XX
	17.01	**17.0**X.XX
	16.03 16.04	**16.2**X.XX
B	22.01 22.02 22.03	**22.1**X.XX
	32.01	**32.4**X.XX
	32.02	**32.3**X.XX
	32.03	**32.2**X.XX
C	21.01 21.02 21.03 21.04	**21.1**X.XX
	41.01 41.02 41.03	**41.1**X.XX
	31.02 31.08	**31.4**X.XX
	31.03 31.07	**31.2**X.XX
	31.04 31.05	**31.3**X.XX
D	27.01 27.02	**27.1**X.XX
	47.04 47.05	**47.1**X.XX **47.2**X.XX
	37.04	**37.1**X.XX **37.2**X.XX
E	28.01 28.02 28.04	**28.1**X.XX
F	13.02	**13.0**X.XX
	23.01	**23.1**X.XX



The first step was to obtain the list of all applicable materials within each building part. As seen in table H1, a list of applicable NL-Sfb elements is provided for each building part. However, only the first two digits of this classification corresponds to NL-Sfb coding system. The next two digits are assigned by DGBC.

In practice either 4 digit NL-Sfb codes or 6-digit STABU coding which is an extension to the NL-Sfb system is generally adopted in the Netherlands. The first step in developing the prototype was to map the MAT5 classification codes to NL-Sfb coding system. All the elements that fall under each code shown in Table H1 correspond to a distinct set of first three digits in NL-Sfb and STABU assembly codes. This relationship is shown in Table H2 and this logic was used to filter the applicable elements.

Once the list of all applicable building elements was obtained, the next step was to get all the materials associated with these elements and filter the insulation materials from this list. This is done because insulation materials are not considered in this part of MAT5 calculation. Insulation materials are filtered by checking the material parameter named “Insulation Material”. Only the list of materials with a parameter value “No” are reported in the final results.

From the final list of materials, all the parameters associated with each material are checked to obtain the value for the parameter “Tier”. And finally, the total volumes of each material and volume per each Tier level are calculated.

To sum up the volume of each material within a building part, the results are grouped for materials with the same building component and Material ID. The calculation formula used in MAT5 excel sheet was used to calculate the total points achieved per each building part. The score of all parts is summed up to obtain the total points and corresponding achievable credits.

```
using System;
using System.IO;
using System.Linq;
using System.Collections.Generic;
using Autodesk.Revit.UI;
using Autodesk.Revit.DB;

namespace REVITPluginMAT5
{
    [Autodesk.Revit.Attributes.Transaction(Autodesk.Revit.Attributes.TransactionMode.Manual)]
    public class Exporter : IExternalCommand
    {
        public Autodesk.Revit.UI.Result Execute(ExternalCommandData revit,
           ref string message, ElementSet elements)
        {
            // IMPORTANT: Ensure correct configuration of manifest file is added to the addin file
            // IMPORTANT: Add correct path for the output in the below line
            string filePath = @"C:\Users\Vyshali\Documents\output.csv";

            // Define the assembly code that needs to be filtered
            List<String> inputCodes = new List<String>();

            inputCodes.Add("16.1");
            inputCodes.Add("17.0");
            inputCodes.Add("16.2");
            inputCodes.Add("22.1");
            inputCodes.Add("32.4");
            inputCodes.Add("32.3");
            inputCodes.Add("32.2");
            inputCodes.Add("21.1");
            inputCodes.Add("41.1");
            inputCodes.Add("31.4");
            inputCodes.Add("31.2");
            inputCodes.Add("31.3");
            inputCodes.Add("27.1");
            inputCodes.Add("27.2");
            inputCodes.Add("47.1");
            inputCodes.Add("47.2");
            inputCodes.Add("37.1");
            inputCodes.Add("37.2");
            inputCodes.Add("28.1");
            inputCodes.Add("13.0");
            inputCodes.Add("23.1");

            // Define the assembly descrptions of the assembly codes
            List<String> inputCodesDescriptions = new List<String>();

            inputCodesDescriptions.Add("Foundation Strips & Footing");
            inputCodesDescriptions.Add("Foundation Piles");
            inputCodesDescriptions.Add("Foundation Walls");
```

```
            inputCodesDescriptions.Add("Interior Walls");
            inputCodesDescriptions.Add("Door and Window Frames (Internal)");
            inputCodesDescriptions.Add("Internal Doors");
            inputCodesDescriptions.Add("Internal Windows");
            inputCodesDescriptions.Add("External Walls");
            inputCodesDescriptions.Add("External Wall Finishes");
            inputCodesDescriptions.Add("Door and Window Frames (External)");
            inputCodesDescriptions.Add("External Windows");
            inputCodesDescriptions.Add("External Doors");
            inputCodesDescriptions.Add("Non-load Bearing Roof");
            inputCodesDescriptions.Add("Load Bearing Roof");
            inputCodesDescriptions.Add("Roof Finishes");
            inputCodesDescriptions.Add("Roof Coverings");
            inputCodesDescriptions.Add("Skylight Frames");
            inputCodesDescriptions.Add("Skylight Grazing");
            inputCodesDescriptions.Add("Columns and Beams");
            inputCodesDescriptions.Add("Floors");
            inputCodesDescriptions.Add("Gallery Floors");

            // Define the building components of the assembly codes
            List<String> inputCodesComponent = new List<String>();

            inputCodesComponent.Add("A");
            inputCodesComponent.Add("A");
            inputCodesComponent.Add("A");
            inputCodesComponent.Add("B");
            inputCodesComponent.Add("B");
            inputCodesComponent.Add("B");
            inputCodesComponent.Add("B");
            inputCodesComponent.Add("C");
            inputCodesComponent.Add("C");
            inputCodesComponent.Add("C");
            inputCodesComponent.Add("C");
            inputCodesComponent.Add("C");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("D");
            inputCodesComponent.Add("E");
            inputCodesComponent.Add("F");
            inputCodesComponent.Add("F");

            // Reference variable to the open project
            Document currentProject =
              revit.Application.ActiveUIDocument.Document;

            // Get all element types from the document
            IList<Element> returnedElementTypes = new FilteredElementCollector
              (currentProject).OfClass(typeof(ElementType)).ToElements();

```

```
            // Output variable to store the list of element types associated with input assembly code
            List<String> filteredElementTypeID = new List<String>();

            // Get list of element types corresponding to the input assembly code
            foreach (Element element in returnedElementTypes)
            {
                // Concatenate the assembly code to the first four characters
                string assemblyCode = element.get_Parameter(BuiltInParameter.UNIFORMAT_CODE).AsString();
                if (assemblyCode.Length > 4) { assemblyCode = assemblyCode.Remove(4); }

                // Check if the assembly code is part of the required list
                if (inputCodes.Contains(assemblyCode))
                {
                    filteredElementTypeID.Add(element.Id.ToString());
                }
            }

            // Remove duplicates in the filter element type list
            List<String> distinctElementTypeID = filteredElementTypeID.Distinct().ToList();

            // Output variable for list of elements corresponding to above list of element types
            List<Element> filteredElements = new List<Element>();

            // Get all elements in the project
            FilteredElementCollector collector = new FilteredElementCollector(currentProject).WhereElementIsNotElementType();

            // Loop through all elements to filter elements by element type
            foreach (Element element in collector)
            {
                if (distinctElementTypeID.Contains(element.GetTypeId().ToString()))
                {
                    filteredElements.Add(element);
                }
            }

            // Output variable for the results table
            List<ElementEntry> fullResults = new List<ElementEntry>();

            // Get list of all data needed from the API and store in the results list
            foreach (Element element in filteredElements)
            {
                // Get element types associated with the element
                ElementType eType = currentProject.GetElement(element.GetTypeId()) as ElementType;
```

```
                // Get all materials associated with the element
                ICollection<ElementId> elementMaterials = element.GetMaterialIds(false);
                // Loop through all the materials in the element
                foreach (ElementId m in elementMaterials)
                {
                    // Get reference to the material object
                    Element material = currentProject.GetElement(m);
                    // Get list of parameters associated with the material
                    ParameterSet mParameters = material.Parameters;
                    // Variable for material tier
                    String mTier = "NA";
                    String filterFlag = "Yes";
                    // Loop through parameters to find material's tier
                    foreach (Parameter p in mParameters)
                    {
                        // Get parameter name and check against "Tier"
                        String pName = p.Definition.Name;
                        if (pName == "Tier") mTier = p.AsValueString();
                        if (pName == "Insulation Material") filterFlag = p.AsValueString();
                    }

                    // Concatenate the assembly code to the first 4 characters
                    String condensedAssemblyCode = eType.get_Parameter(BuiltInParameter.UNIFORMAT_CODE).AsString();
                    if (condensedAssemblyCode.Length > 4) { condensedAssemblyCode = condensedAssemblyCode.Remove(4); }

                    // Find the corresponding building component
                    String entryBuildingComponent = inputCodesComponent[inputCodes.IndexOf(condensedAssemblyCode)];

                    if (filterFlag == "No")
                    {
                        // Add entry to the results table
                        fullResults.Add(new ElementEntry()
                        {
                            buildingComponent = entryBuildingComponent,
                            elementID = element.Id.ToString(),
                            elementTypeID = eType.Id.ToString(),
                            materialID = material.Id.ToString(),
                            materialName = material.Name,
                            materialTier = mTier,
                            materialVolume = Math.Round(element.GetMaterialVolume(m) * 0.028316846592, 2)
                        });
                    }
                }
            }

            // Group results by unique bulding components and materials
```

```
            var groupResults = from s in fullResults group s by new { s.buildingComponent, s.materialID };

            // Store results in the final results list
            List<ResultEntry> results = new List<ResultEntry>();

            // Loop through final list to add to results list
            foreach (var group in groupResults)
            {
                // Calculate the total volume of the specific material in the building component
                double totalVolume = 0;
                foreach (var e in group) totalVolume += e.materialVolume;

                // Convert the volumne in five individual columns (as required in output)
                double[] volumes = new double[5] { 0, 0, 0, 0, 0 };
                switch (group.First().materialTier)
                {
                    case "1":
                        volumes[1] = totalVolume;
                        break;
                    case "2":
                        volumes[2] = totalVolume;
                        break;
                    case "3":
                        volumes[3] = totalVolume;
                        break;
                    case "4":
                        volumes[4] = totalVolume;
                        break;
                    default:
                        volumes[0] = totalVolume;
                        break;
                }

                // Add the data to a list for easy processing
                results.Add(new ResultEntry()
                {
                    buildingComponent = group.First().buildingComponent,
                    materialID = group.First().materialID,
                    materialName = group.First().materialName,
                    volumeTier0 = volumes[0],
                    volumeTier1 = volumes[1],
                    volumeTier2 = volumes[2],
                    volumeTier3 = volumes[3],
                    volumeTier4 = volumes[4]
                });
            }

            // Sorting the results
            results = results.OrderBy(o => o.buildingComponent).ThenBy(o =>
```

```
                o.materialID).ToList();

            // Calculating the building component summary
            var summary = results.GroupBy(e => e.buildingComponent)
                .Select(g => new SummaryEntry
                {
                    buildingComponent = g.Key,
                    volumeTier0 = g.Sum(x => x.volumeTier0),
                    volumeTier1 = g.Sum(x => x.volumeTier1),
                    volumeTier2 = g.Sum(x => x.volumeTier2),
                    volumeTier3 = g.Sum(x => x.volumeTier3),
                    volumeTier4 = g.Sum(x => x.volumeTier4)
                });

            // Variable to store the building score
            double fullScore = 0;

            // Group the entries by the building components to add to the output with summary line
            var groupedResults = from s in results group s by new { s.buildingComponent };

            // Building CSV header line
            String printOutput = "Building Part, Material, Total Volume, Tier 1 Volume, Tier 2 Volume, Tier 3 Volume, Tier 4 Volume, Points\n";

            // Add each building group to the output with a additional summary line
            foreach (var group in groupedResults)
            {
                // Add the material information lines for the give building component
                foreach (ResultEntry r in group)
                {
                    // Build the line corresponding to the unique building component and material
                    double totalMaterialVolume = r.volumeTier0 + r.volumeTier1 + r.volumeTier2 + r.volumeTier3 + r.volumeTier4;
                    printOutput += r.buildingComponent.Replace(",", string.Empty) + ","
                      + r.materialName.Replace(",", string.Empty) + ","
                      + totalMaterialVolume.ToString() + ","
                      + r.volumeTier1.ToString() + ","
                      + r.volumeTier2.ToString() + ","
                      + r.volumeTier3.ToString() + ","
                      + r.volumeTier4.ToString() + ","
                      + ","
                      + "\n";
                }
                // Find the corresponding entry in the summary variable for the building component
                var e = summary.Where(s => s.buildingComponent == group.First
```

```
                ().buildingComponent).First();
            // Add the summary line to the output
            double totalVolume = e.volumeTier0 + e.volumeTier1 + e.volumeTier2 + e.volumeTier3 + e.volumeTier4;

            // Calculate the adjusted tier volume percentages
            double adjustedTier1 = Math.Min(100, (e.volumeTier1 * 100) / (totalVolume * 0.8));
            double adjustedTier2 = Math.Min(100, (e.volumeTier2 * 100) / (totalVolume * 0.8));
            double adjustedTier3 = Math.Min(100, (e.volumeTier3 * 100) / (totalVolume * 0.8));
            double adjustedTier4 = Math.Min(100, (e.volumeTier4 * 100) / (totalVolume * 0.8));

            // Limited based on the BREEAM calculation
            double limiterTier1 = adjustedTier1;
            double limiterTier2 = Math.Min(adjustedTier2, 100 - adjustedTier1);
            double limiterTier3 = Math.Min(adjustedTier3, 100 - (adjustedTier1 + adjustedTier2));
            double limiterTier4 = Math.Max(0, Math.Min(adjustedTier4, 100 - (adjustedTier1 + adjustedTier2 + adjustedTier3)));

            // Final score for the component is calculated
            double componentScore = 3 * limiterTier1 + 2 * limiterTier2 + 1.5 * limiterTier3 + limiterTier4;
            componentScore /= 100;

            // If the Tier 0 materials are more than 20%, assign a score of 0
            if (e.volumeTier0 / totalVolume > 0.2) { componentScore = 0; }

            // Add the component score to the building score
            fullScore += componentScore;

            // Add the summary line of the component to the output
            printOutput += e.buildingComponent.Replace(",", string.Empty) + ","
                + "BUILDING PART_TOTAL, "
                + totalVolume.ToString() + ","
                + e.volumeTier1.ToString() + ","
                + e.volumeTier2.ToString() + ","
                + e.volumeTier3.ToString() + ","
                + e.volumeTier4.ToString() + ","
                + componentScore.ToString() + ","
                + "\n";
        }
        // Add the final building score to the output file
        printOutput += "\nMAT 5 Total Points, , , , , , ," + fullScore.ToString() + "\n";

        // Find the final credits acheived
```

Appendix J- Manual assessment results

A. **Comparison of material quantities from REVIT take-off and prototype plugin**

Building Part	Material	Volume in cu.m	
		Plugin result	REVIT take-off
B	aluminium mullion	1.72	-
B	Aluminum_grey	0.3	-
B	Glass_clear_transparent	8.21	7.09
B	Wood_white_interior windows	3.44	3.44
B	PVC Flexible	0.32	0.32
B	HPL_panel_sanitairy partion walls	1.22	1.22
B	sand-lime stone	52.41	52.41
B	metal (ESP)	0.04	0.04
B	air	5.33	5.33
B	gypsum_board	55.98	55.98
B	Wood_white_interior doors	5.79	5.79
B	BUILDING PART_TOTAL	134.76	
C	concrete_precast	4.52	4.52
C	glass_facade panel_green_1	0.35	0.35
C	glass_facade panel_red_1	0.32	0.32
C	glass_facade panel_yellow_1	0.3	0.3
C	Wood_plywood	5.8	5.8
C	Glass_clear_transparent	11.52	8.87
C	aluminum_facade_cassettes_white	2.57	2.57
C	hardwood decking boards	0.17	0.17
C	cement_back plate_glass panel	10.59	10.59
C	aluminum_windows_external	11.39	1
C	sand-lime stone	58.68	58.68
C	glass_facade panel_red_2	0.31	0.31
C	glass_facade panel_red_3	0.35	0.35
C	glass_facade panel_green_2	0.31	0.31
C	glass_facade panel_green_3	0.32	0.32
C	glass_facade panel_yellow_2	0.28	0.28
C	glass_facade panel_yellow_3	0.31	0.31
C	Wood_white_interior doors	0.68	0.68
D	Glass_clear_transparent	0.34	0.34
D	aluminum_windows_external	0.03	0.03
D	aluminium dakbedekking	3.38	3.38
D	Gorter_Material 1	0.17	0.17
D	Gorter_Material 2	0.11	0.11
E	steek (stair)	0.05	0.05
E	Wood_common	2.21	2.21
E	steel_galvanized	2.64	2.21
E	steel_stainless	0	0
F	Wood_common	2.96	2.96
F	hardwood decking boards	9.52	9.52

B. Calculation of final credits in the manual assessment method

Element		Materiaal types	Volume van relevante materialen aanwezig	Volume van materialen in overeenstemming met Tier niveau: Tier 1	Tier 2	Tier 3	Tier 4	% van totaal welke overeenkomt met Tier 1-4 (min. 80%)	Totaal Punten / Element
HOOFDBOUWDEEL A		Selecteer het aantal elementen die u wenst in te voeren (en klik op 'select'):	0		Select			0.00	0.00
HOOFDBOUWDEEL B		Selecteer het aantal elementen die u wenst in te voeren (en klik op 'select'):	2		Select			94.87	1.22
ELEMENT 1									
	Mat 1	aluminium mullion	1.72	0	0	1.72	0		
	Mat 2	Aluminum_grey	0.3	0	0	0.3	0		
	Mat 3	Glass_clear_transparent	8.21	0	0	8.21	0		
	Mat 4	Wood_white_interior windows	3.44	3.44	0	0	0		
	Mat5	PVC Flexible	0.32	0	0	0	0		
	Mat 6	HPL_panel_sanitairy partion walls	1.22	0	0	0	0		
	Mat 7	sand-lime stone	52.41	0	0	0	52.41		
	Mat 8	metal (ESP)	0.04	0	0	0	0		
		Totaal % element beoordeeld	97.66%		Totaal volume element		67.66		
ELEMENT 2									
	Mat 1	air	5.33	0	0	0			
	Mat 2	gypsum_board	55.98	0	0	0	55.98		
	Mat 3	Wood_white_interior doors	5.79	5.79	0	0	0		
	Mat 4								
	Mat5								
	Mat 6								
	Mat 7								
	Mat 8								
		Totaal % element beoordeeld	92.06%		Totaal volume element		67.10		
HOOFDBOUWDEEL C		Selecteer het aantal elementen die u wenst in te voeren (en klik op 'select'):	3		Select			98.27	1.42
ELEMENT 1									
	Mat 1	concrete_precast	4.52	0	0	0	4.52		
	Mat 2	glass_facade panel_green_1	0.35	0	0	0	0.35		
	Mat 3	glass_facade panel_red_1	0.32	0	0	0	0.32		
	Mat 4	glass_facade panel_yellow_1	0.3	0	0	0	0.3		
	Mat5	Wood_plywood	5.8	5.8	0	0	0		
	Mat 6	Glass_clear_transparent	11.52	0	0	11.52	0		
	Mat 7	aluminum_facade_cassettes_white	2.57	0	0	2.57	0		
	Mat 8	hardwood decking boards	0.17	0.17	0	0	0		
		Totaal % element beoordeeld	100.00%		Totaal volume element		25.55		
ELEMENT 2									
	Mat 1	cement_back plate_glass panel	10.59	0	10.59	0	0		
	Mat 2	aluminum_windows_external	11.39	0	0	11.39	0		
	Mat 3	sand-lime stone	58.68	0	0	0	58.68		
	Mat 4	glass_facade panel_red_2	0.31	0	0	0	0		
	Mat5	glass_facade panel_red_3	0.35	0	0	0	0		
	Mat 6	glass_facade panel_green_2	0.31	0	0	0	0		
	Mat 7	glass_facade panel_green_3	0.32	0	0	0	0		
	Mat 8	glass_facade panel_yellow_2	0.28	0	0	0	0		
		Totaal % element beoordeeld	98.09%		Totaal volume element		82.23		
ELEMENT 3									
	Mat 1	glass_facade panel_yellow_3	0.31	0	0	0	0		
	Mat 2	Wood_white_interior doors	0.68	0.68	0	0	0		
	Mat 3								
	Mat 4								
	Mat5								
	Mat 6								
	Mat 7								
	Mat 8								
		Totaal % element beoordeeld	68.69%		Totaal volume element		0.99		
HOOFDBOUWDEEL D		Selecteer het aantal elementen die u wenst in te voeren (en klik op 'select'):	1		Select			0.81	0.00
ELEMENT 1									
	Mat 1	aluminum_windows_external	0.03	0	0	0.03	0		
	Mat 2	aluminium dakbedekking	3.38	0	0	0	0		
	Mat 3	Gorter_Material 1	0.17	0	0	0	0		
	Mat 4	Gorter_Material 2	0.11	0	0	0	0		
	Mat5							geen punten, totaal is < 80%	
	Mat 6								
	Mat 7								
	Mat 8								
		Totaal % element beoordeeld	0.81%		Totaal volume element		3.69		

Figure I1 Results from Manual assessment method- Part 1

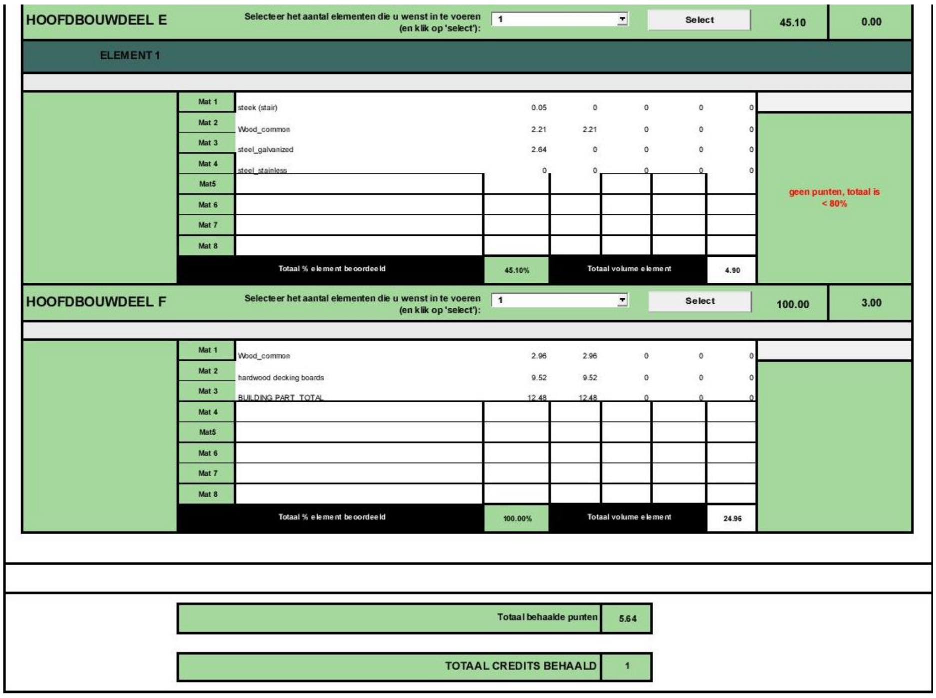


Figure I2 Results from Manual assessment method- Part 2

Appendix K – Validation interviews

Interview questions:

Recommendations

1. What do you think about the feasibility of the proposed recommendations for Deerns from an internal perspective? (Given the culture of the organization, technical and human resources available, is it a feasible solution?)
2. What do you think about the feasibility of the proposed recommendations from an external perspective i.e., support from other project teams and client?
3. What do you think about the general recommendations proposed for the company and the author's suggestion to initiate the transition to BIM stage 2?
4. The recommendations were elaborated for one example credit – MAT05. How would you assess its usefulness in practice? (Based on time and effort that goes into the current way of assessment)

Improvements and Changes

1. Are there any critical issues/ potential risks that were overlooked in this research?
2. Do you have any suggestions for improvement of the proposed recommendations?

Research Value

1. What practical value do you think will this research bring to your team and organization?
2. Open question – final comments

Interview results:

B3 P

Feasibility internal: Feasibility of implementation from an internal perspective is quite high provided that the benefits are clearly conveyed to the team members. As far as the culture goes, the energy team is quite young and open to new methods. But we do not know of all the possibilities with BIM and how to systematically approach the implementation aspects. I think that the process and policy related recommendations are very important for the implementation part. More than the technology itself.

Of course the implementation takes time and will be an iterative process. The main hurdle is that the team members of energy team do not know BIM well enough to start implementation by themselves. For long-term, I think using BIM is not a choice, but rather essential to remain competitive.

But regarding collaboration with the BIM department and the continuation of this implementation strategy is challenging. Because these kind of projects require a dedicated person working on this topic. The BIM department has the knowledge about BIM but do not know our work well enough to lead this process. So we will need someone who is an expert in both BREEAM-NL and digitalization. It is not an easy task to do and therefore we need full focus and commitment in this project.

External feasibility: External feasibility will not be a problem because this bears benefits for the client and other teams as well. There are certain credits for which architects/ other project team members do the assessments. Therefore, if we can provide them a smarter way of doing this, they will be on board. For the client, the possibility of checking BREEAM status at any point of time is a great benefit.

Decision to move to stage 2: I think BIM implementation steps have to be take step-by-step. Technology can evolve fast, but not people and processes. Currently I don't think industry in general is at Stage 3 maturity, but rather at stage 2. And we're lagging in this aspect. Therefore, I think it is smart to first catch up to speed by moving to stage 2 and aim for stage 3 when the industry is general.

Use in practice: I think the results of this project can have an immediate use for our process. There are a lot of mundane tasks done in a manual way when there is a much smarter way of doing it.

Concluding remarks: The important thing about this research project is that it connects two different knowledge fields. One critical issue is that we are dependent on the BIM department for the technology part of its implementation. The strategy has to be long-term with regards to the kind of tools to use and the logic in coding. Also, having only one internal BIM person is risky as the knowledge will be lost if this person leaves the organization. The implementation plan has to be standardised at an organizational level. The long-term ambition for BIM has already been declared, but the responsibilities of implementation have to be assigned.

B2

Internal feasibility: I think that internally the recommendations are feasible, especially starting with the most time consuming ones. The main hurdle would be the culture of the organization. We like to do things the way we do now, and BIM is a little bit out of comfort zone. But energy team is quite young and eager to learn, therefore it should be feasible.

External feasibility: I think it is feasible, but time taking. When it comes to BREEAM team, the communication and information delivery is mostly PDF based. That's because the final submissions are PDF based and therefore the design teams don't give information through BIM models.

Decision to move to stage 2: It's certainly a good idea to take it step wise. We can always switch to a fully BIM based workflow later, but I think starting with the most critical credits would in itself be a big win.

Use in practice: I think the biggest advantage would be the ability to verify the compliance immediately and as many times as needed. Normally we make the assessments at the end of each design phase and sometimes it's too late to make adjustments to the design.
Potential risks: No major risks that aren't already discussed. This is a good starting point, but we have to follow up on it.

B10

Internal feasibility: Needs of the BREEAM-NL team must be known. What are their assessment methods, input parameters and who gives them? How many times do they need to do these assessments?

This is a big step from the current situation. Moving step by step is a good idea, aiming for stage 3 directly would not work in practice.
Adequate hardware support is currently available only on limited systems. But this is not a problem, it can be extended.

External feasibility: Not sure how the other project teams would react. BREEAM Team is relatively a small party so their influence might not be as high as the other players. So what benefits do the other teams have with this intervention?

Starting with adding these new requirements in the BIM protocol is a better approach to ensure cooperation.
We can probably take steps to help the external parties get on board i.e., explain them how the tool works and what they need to do in detail.
Depends upon the scale of the project. In small projects if the project teams are not using BIM extensively, then this will not work. What is the general scale of projects handled by BREEAM Team?

Potential risks: Nothing major; really depends upon the people using the tools and how welcome they are to change. BREEAM team is a young one, so I don't expect resistance whereas rest of Deerns, the older employees are not in favour of BIM.

B9
Internal feasibility: It is always a good idea to automate tasks, but for large scale implementation, a business case would be required. From this perspective, Stage 2 is where the investments are more effective. BREEAM team is a small part of the overall organization, therefore
Also, for the BIM team to be able to help with the technical infrastructure, documentation of current assessment process, tools used and number of times the tasks are repeated is needed.

External feasibility: As long as we're not asking too much of the external parties and it does not cost them extra hours, it should be feasible. So we need to keep the additional requirements to minimum. Providing inputs for BREEAM is a part of the job description of the external parties. As long as the requirements are made clear and at the beginning of a project, it will work.

Usefulness in practice: In general BE team has not been actively involved in a lot of BIM initiatives. So for me, having a clear idea of their workflow and automation needs this research provides is a first step towards initiating implementation activities.

B4
Internal feasibility: I think tackling the most time consuming credits is a good idea. From a business perspective, these are also the credits we lose money on. The Energy team is very young, therefore there is not much resistance towards change. But we would need someone from the BIM team dedicated to this digitalization project for the follow up steps.

External feasibility: I think it is feasible, as long as it is not costing the client more money. Also depends on how you propose the changes. If the benefits to the client and other project teams are conveyed well, it

Usefulness in practice: From an efficiency perspective, it is quite useful due to the time savings that can be expected out of automation. The possibility of getting immediate feedback during the design process is also quite useful.