SUSTAINABLE GREEN BUILDING CERTIFICATIONS SUPPORTED BY BUILDING INFORMATION MODELLING

Master thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

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International Master of Science in Construction and Real Estate Management Joint Study Programme of Metropolia Helsinki and HTW Berlin

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University of Applied Sciences

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Conceptual Formulation

Master Thesis for ~~Mr.~~ /Ms. ADERONKE .O. LANISA

Student number S0557528

Topic: SUSTAINABLE BUILDING CERTIFICATIONS SUPPORTED BY BUILDING INFORMATION MODELLING (BIM).

EXECUTIVE SUMMARY: This research evaluates the practicalities of different attributes and standards of sustainable building certificates and how they are being supported by BIM. This is achieved by making an in-depth comparison of the similarities, differences and roles played by these attributes, infusing these characteristics in a BIM reference model to upgrade its standards for the award of green building certification.

BACKGROUND: Buildings have a huge impact on the environment in all the stages of their existence. They consume and emit large amounts of energy which in turn contributes to the degradation of the whole environment for example greenhouse effect and depletion of the ozone layer. In an attempt to reduce these impacts on the environment, building sustainability was introduced.

Sustainability is therefore anything that is done to reduce harmful effects caused while considering to improve the opportunities of the future without compromising them. Sustainability is no longer an idea but gradually becoming an important aspect of the built environment. It is not strange to have buildings being rated and awarded with sustainable certificates. The concept behind the creation of green building standards, certifications, and rating systems is aimed at mitigating the impact of buildings on the natural environment through sustainable design. [1]

According to Ebert et al, Certification systems for buildings aim to make sustainability crystal and easy to compare. However, these systems depend on dynamic development, as it is obvious that these systems are in competition with one another [2]

AIM

To incorporate all sustainable characteristics or attributes needed for sustainability certification and rating of a building into BIM.

OBJECTIVES

1. To create a comparison between all attributes of different green certification systems.
2. To work out evaluations needed for sustainability building rating by defining the level of attributes needed in a BIM reference model that will make it fit for certification.
3. To support building energy simulation and efficiency by integrating it earlier into the planning process through BIM.
4. To improve the long-term value of a building sustainably.

RESEARCH QUESTIONS

1. What are the different attributes that must be present in a building to attain a green certification?
2. How can the standards be applied universally into the BIM system?
3. How can these attributes be incorporated into the planning process to make it faster?
4. Will a comparative analysis of the different sustainability building rating systems make building evaluation more efficient?

METHODOLOGY

Primarily, data collation will be by intensive research on the comparative analysis of different sustainability rating systems for building certification through evaluation of their attributes, characteristics, standards and incorporating these findings into an existing BIM reference model which will serve as the case study for this report. Examination of secondary data method will involve data collection from books, journals, recorded videos, online internet sources and many more.

TIME FRAME

The master's thesis will commence on 12th February 2018 and will last for 20 weeks.

3 weeks: Study the key contents and create an outline

3 weeks: Literature review

4 weeks: Gathering primary data

2 weeks: Evaluation of case studies

5 weeks: Data analysis and writing the technical section

3 weeks: Research conclusion, assessment and colloquium

The dissertation will be presented at the colloquium to be decided later. Both supervisors will be present at the colloquium.

REFERENCES

[1] S. Vierra, "Green buildings standards and certification systems," 12 09 2016. [Online]. Available: https://www.wbdg.org/resources/green-building-standards-and-certification-systems. [Accessed 14 12 2017].

[2] T. Ebert, N. Essig and G. Hauser, Green certification systems, Regenburg: Aumuller Druck, 2011.

Signature of the Supervisor

Abstract

The impact of the activities of man on the environment especially in the construction industry is undeniably huge. Our immediate environment today is mostly covered by buildings and structures. These buildings in turn consume and emit large amounts of energy throughout their lifecycle thereby posing numerous threats to the environment. Over the years, measures have been taken to mitigate or eliminate the sources and effects of these impacts on the environment. These measures aim at restoring the 'greenness' and purity of the natural environment as much as possible. This process is alternatively, known as sustainability. Previously, there has been a lot of studies and researches sustainability practices. One method that has contributed tremendously to restoring the sustainability of the environment is by awarding Sustainable building certifications to the buildings. These are certificates awarded to buildings because of the sustainable practices involved in the process and meeting the standards of the rating system. This research is aimed at evaluating the attributes, criteria sets, weights and credits required to earn a certain level of green certification and how they can be supported by the implementation of Building information modelling.

The rating systems used in this research were selected due to their popularity in Europe. They include: BREEAM; LEED; DGNB and HQE. The criteria sets for these certification systems were analyzed and a comparative analysis was done to compare these rating systems, their requirements, credits and BIM implementation.

First of all, a background study of previous literature on this issue was done giving an overview of the sustainability rating systems and BIM. Next, a short exposition of BIM and Green BIM was done showing the status quo, application and future projection of BIM into sustainability. Then a comparative analysis of these systems based on certain parameters was made such as categories, similarities, rating systems. The results of the analysis made were evaluated in relation to and an existing already awarded LEED platinum building in Berlin. From the results of the evaluation, conclusions and recommendations for improving the present status as well as projections for future use of BIM in sustainability certification were deduced.

Key words: Sustainability, Rating systems, Building information modelling, Certifications, Comparative analysis.

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List of Abbreviations

2D	2- Dimensional
3D	3-Dimensional
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BIM	Building Information Modelling
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Design
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen eV
DWG	Data Working Group
DXF	Drawing Exchange Format
FIG	Figure
GBS	Green building system
gbXML	Green Building XML
GFA	Gross floor area
GHE	Green House effect
HQE	Haute qualité environnementale
HVAC	Heating, ventilation, and air conditioning
IDA ICE	IDA Indoor Climate and Energy
IES-VE	Integrated Environmental Solution – Virtual Environment
IFC	Industry Foundation Classes
IGES	Initial Graphics Exchange Specification
LOD	Level of Development
MVD	Model view Definition
MEP	Mechanical, Electrical and Plumbing
TRNSYS	Transient System simulation software
UI	User Interface

1.0. Introduction

1.0. Overview of study

Almost eighty percent of our environment today is covered by the built-up space. Buildings therefore, are an integral part of the environment. Due to the amount of energy these structures consume and emit at the same time, they gradually impose a threat to the natural ecology and landscape. Therefore, it has become imperative to include sustainability considerations when designing and constructing buildings. Sustainability is simply designing for the present with the future in mind. The AEC industry has a huge task to validate the sustainability of new buildings and existing buildings alike. The approach to achieving this within the industry has become widely structured since the creation of Green building certification systems, also known as Sustainable rating systems. To stablish and recognize these sustainable practices within the AEC industry, it is common practice now to have buildings been rated and awarded a green certificate. As ridiculous as it might seem, these certifications help to promote sustainability and give a sense of "safety" to building users. However, the AEC industry did not only stop at implementing green certifications but went further to creating BIM software that will support these certifications, enhance the interoperability between planners, in order to ease the rigorous activity of building planning and design as well as making the building sustainability a common practice today.

1.1. Aim and objectives

Aim: To analyse and compare various sustainable attributes required for certification and how it can be supported by building information modelling.

Objectives

i. To create a comparison between all attributes of different green certification systems.
ii. To work out evaluations needed for sustainability building rating by defining the level of attributes needed in a BIM reference model that will make it fit for certification.
iii. To support building energy simulation and efficiency by integrating it earlier into the planning process through BIM.

iv. To improve the long-term value of a building sustainably.

1.2. Statement of problem

The importance of building sustainability in our world today cannot be overemphasized. It has gradually become a requisite in obtaining approval for the construction of buildings especially, residential and public buildings. From its basic form such as consideration of ventilation and natural lighting in buildings to its complex forms such as energy simulation and consumption calculations. Therefore, the need for meticulous consideration of green attributes, characteristics and standards earlier on in the building design process is paramount. This is where BIM comes into play. BIM is a vital computer aided tool in the design of buildings and structures today. With a wide range of software applications, BIM is the future of building design. As a result, this research will attempt to strike a balance and impose a merging point to how BIM can support a building design in attaining the award of various sustainable green certificates.

1.3. Significance of study

Effective distribution of information among team members within a project is very important as it determines the duration and quality of the outcome of that project among many other factors. Since the concept of BIM is relatively new compared to building sustainability, this research would be helpful in providing the needed information to project teams and professionals alike about the relationship, differences and similarities between planning and design decisions and the green credits to be attained.

It would also give a better understanding of how sustainability decisions affect or enhance the design of buildings from an early stage.

1.4. Research methodology

Primarily, data collation was by an intensive research on the comparative analysis of different sustainability rating systems for building certification through evaluation of their attributes, characteristics, standards and incorporating these findings into an existing BIM reference model which served as the case study for this report. Secondary data was collated from books, journals, recorded videos, online internet sources and other relevant data to this research.

1.5. Structure of research

This research is focused on attaining green certification for a building by;

- A comparative analysis of the various existing attributes of different building sustainable rating systems such as LEED, DGNB, BREEAM and HQE[1] in tabular form.
- A study on how these attributes can be supported by BIM.
- A case study of the EUREF Campus Haus 12-13 3D model was extensively carried out for the purpose of this study.
- BIM tools such as Autodesk Revit architecture, IDA ICE, Simple BIM were analysed and utilized in the course of this research.
- An analysis of the sustainable attributes required to obtain certification for a building was extensively discussed.

[1] (Sadrykia, et al., 2016) (Portalatin, 2010)

2.0. BACKGROUND AND LITERATURE REVIEW

2.1. Sustainable rating systems

In recent times, there has been a global concern over the limitations of raw materials and energy resources. This was attributed to many factors among which global warming played a huge role. The rise of this concern led to the creation of a number of methods and systems established to assess and measure the success of buildings against environmental criteria. (Sadrykia, et al., 2016) [2]

A voluntary environmental assessment method was established by the Building Research Establishment BRE in 1990, BREEAM. With the aim of objectively measuring the environmental performance of new and existing buildings in the United Kingdom; more precise goals were set for buildings to have a better rating instead of being simply designed to just to meet code requirements. The BREEAM gradually became structured and designers worked more to achieve more improved building performance. Over the years, it was further improved on and the standards were adopted by other countries and many organizations around the world hence, resulting into the creation of many other assessment methods which evolved into what is widely known as Sustainable rating systems today. (Portalatin, 2010)[3]

Sustainable rating systems are tools that investigate the performance or expected performance of a 'building' based on certain criteria and translates the results into an assessment that allows comparison with other buildings. For a rating system to add value to the sustainable design and operation of a building, it must offer a reliable, consistent basis for comparison, evaluate relevant technical aspects of sustainable design, and not be over-burdensome to execute and communicate. (Fowler & E.M. Rauch, 2006)[4]

[2] (Sadrykia, Medghalchi, & Mahdavinejad, 2016)
[3] (Portalatin, 2010)
[4] (Fowler & E.M. Rauch, 2006)

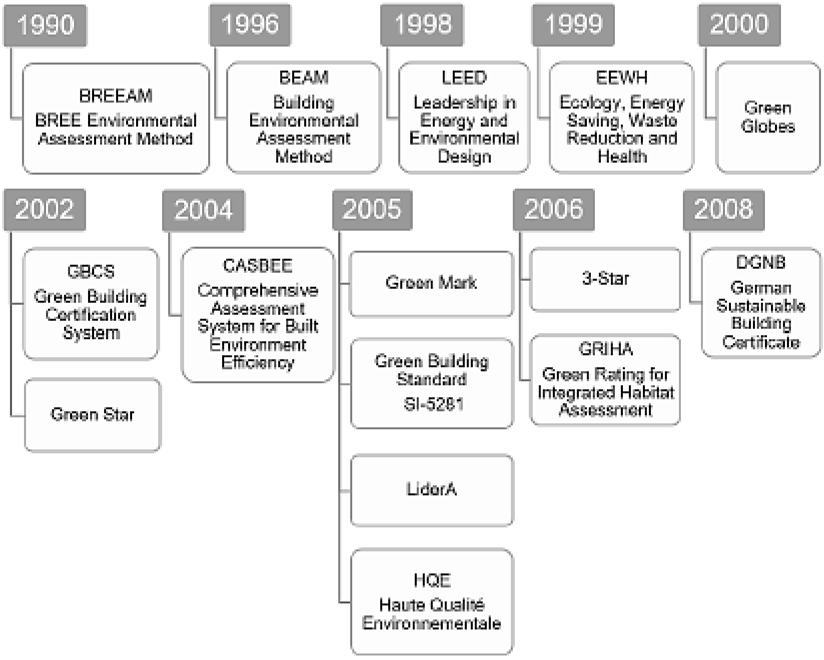

Fig. 1 Rating systems time line.

Rating systems have developed mainly due to the feedbacks received from users and introduction of new technology to enhance the performance of buildings. Although it started out as a voluntary measure of environmental performance, certification is now almost mandatory for buildings in most countries of the world.

Currently available throughout the world are fifteen rating systems that offer certifications, and more are in the pilot stages of development. Three systems are globally recognized as they are currently available for buildings located outside their home countries. They include BREEAM, LEED and Green globes. (Portalatin, 2010)

Fig. 2: Exemplarische Übersicht der Zertifizierungssysteme mit Jahreszahl

Rating systems measure relative levels of compliance or performance against goals and requirements to create projects that are environmentally responsible and use resources efficiently throughout the project lifecycle.

The benefits of green rating system include:

- Environmental objectives can be set.
- Clear goals can be achieved.
- Environmental performance is easily tracked.
- Environmental performance can be demonstrated to third parties.
- Growth can be measured and demonstrated.
- Green education can be supported and improved. (DesigningBuildings, 2017)[5]

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[5] Green building rating systems, 2017

Scoring methods for sustainable rating systems.

To achieve a standard in the assessment of buildings, scoring systems were created based on the following components. The structure is adopted by all rating systems for building assessment. However, when the details are examined, specific adaptations may result in several significant parts.

- Categories: these form a specific set of items relating to the environmental performance considered during the assessment.
- Scoring system: this is a performance measurement system that accrues the number of possible points or credits that can be earned by achieving a given level of performance in several analyzed aspects.
- Weighting system: refers the importance assigned to each specific category within the overall scoring system.
- Output: this aims at showing, in a direct and complete way, the results of the environmental performance obtained during the scoring phase. (Bernardi, et al., 2017)[6]

2.1.1. Building Research Establishment Environmental Assessment Method (BREEAM)

Established by the Building Research Establishment BRE Global Ltd United Kingdom in the year 1900. As the pioneer rating system, it is the most widely used certification system for sustainable construction hence, providing a benchmark for sustainable design and construction. BREEAM currently has in her portfolio over 500 000 certificates, 2,272,983 registered buildings in 77 countries of the world. With this wealth of experience, it is accurate to be rated as the world's leading sustainability assessment method for master planning projects, infrastructure and buildings. BREEAM is used to assess performance in the built environment lifecycle from new construction to in/use and refurbishments. (BRE, 2018)[7]

[6] Bernardi, Carlucci, Cornaro, & Andre´ Bohne, 2017
[7] BRE, 2018

ASSESSMENT SCHEMES AND STANDARDS

These are commonly referred to as the technical standards in the BREEAM certification program. There are five existing standards. They include;

- **Communities for Master planning:** This involves the assessment of large scale developments where the economic and social aspects, besides the environmental aspect, are considered.
- **Infrastructure** – Civil engineering and public realm
- **New construction** – Homes and commercial buildings:
- **In-use** – Commercial buildings: assessment of the sustainable processes executed by commercial buildings during utilization phase.
- **Refurbishment and Fit-out** – Homes and commercial buildings.

ASSESSMENT CATEGORIES: BREEAM awards a quality seal in four grades of sustainable values according to a simple point system in ten evaluation categories. There are currently ten categories in the series and they include;

1. Energy
2. Health and well being
3. Innovation
4. Land use
5. Materials
6. Management
7. Pollution
8. Transport
9. Waste
10. Water

(Sadrykia, et al., 2016)[8]

[8] (Sadrykia, et al., 2016)

Categories	Average weighting%	Credit available	Issues (credits)
Management	• 12	• 20	Man 01: Project brief and design Man 02: Life cycle cost and service life planning Man 03: Responsible construction practices Man 04: Commission and handover Man 05: Aftercare
Health and wellbeing	• 18	• 12.5	Hea 01: Visual comfort Hea 02: Indoor air quality Hea 03: Thermal comfort Hea 04: Microbial contamination Hea 05: Acoustic performance Hea 06: Safe access Hea 07: Natural Hazards Hea 08: Private space Hea 09: Moisture protection
Energy	• 22	• 19	Ene 01: Energy efficiency Ene 02: Energy monitoring Ene 03: External lighting Ene 04: Low and zero carbon technologies Ene 05: Energy efficient cold storage Ene 06: Energy efficient transportation systems Ene 07: Energy efficient laboratory systems Ene 08: Energy efficient equipment Ene 09: Drying space Ene 23: Energy performance of building structure and installations
Transport	• 9	• 10	Tra 01: Public transport accessibility Tra 02: Proximity to amenities Tra 03: Alternative modes of transport Tra 04: Maximum car parking capacity

			Tra 05: Travel plan Tra 06: Home office
Water	• 8	• 5	Wat 01: Water consumption Wat 02: Water monitoring Wat 03: Water leak detection and pre-vention Wat 04: Water efficient equipment
Materials	• 11	• 13.5	Mat 01: Life cycle impacts Mat 02: Responsible sourcing of ma-terials Designing for robustness
Waste	• 6	• 7.5	Wst 01: Construction waste manage-ment Wst 02: Recycled aggregates Wst 03: Operational waste Wst 04: Speculative floor and ceiling finishes
Land Use and Ecology	• 10	• 10	LE 01: Site selection LE 02: Ecological value of site and protection of ecological features LE 04: Enhancing site ecology LE 05: Long term impact on biodiver-sity LE 06. Building footprint
Pollution	• 13	• 8	Pol 01: Impact of refrigerants Pol 02: No emissions Pol 03: Surface water run off Pol 04: Reduction of night time light pollution Pol 05: Noise attenuation
Innovation (additional)	• 10	• 10	

Table 1: *BREEAM Categories, Credits & Issues*. (BREEAM, 2016)

Each of the above listed categories address the most influential factors such as;

- Low impact design and carbon emissions reduction
- Design durability and resilience
- Adaption to climate change
- Ecological value and biodiversity protection

Points are awarded in line with these categories reaching a total of 109 credits. The points are distributed in each category, whereby the combination also plays a role, so that due to different weighting, individual points are added together to a total score. The points are categorized as follows.

Fail = Less than 30

Good =45

Very good = 55

Excellent = 70

Outstanding = >85.

The criteria consider impacts at the global, regional, local and internal levels. BREEAM originally evaluated the stages from design to execution to use. In 2008, a comprehensive amendment was made, which now takes into account the entire life cycle also introduces a changed weighting of environmental impacts and mandatory points. (Baunetzwissen, 2017)[9]

ASSESSMENT AND CERTIFICATIONS

Assessment and certification can take place at various stages in the built environment life cycle from design and construction to operation and refurbishment. This operation is overseen by an independent sustainability board of impartial experts majorly consisting a wide range of stake holders in the construction industry.

[9] (Baunetzwissen, 2017)

To attain certification, the first step is to have a pre-assessment of the building completed by a BREEAM pre-assessment estimator. The pre-assessment estimator will explain the BREEAM process and determine which scheme the building should be assessed under. (Portalatin, 2010) page 12[10]

After the correct scheme has been determined, the next is to decide what the level, improved processes, and the addition of alternative energy sources and more, the certification levels include:

- Pass, requiring a rating of 30%
- Good, requiring a rating of 45%
- Very good, requiring a rating of 55%
- Excellent, requiring a rating of 70%
- Outstanding, requiring a rating of 85%

Minimum Standards – mandatory credits

BREEAM issue	PASS	GOOD	VERY GOOD	EXCELLENT	OUTSTANDING
Man 01: Sustainable procurement	One credit	One credit	One credit	One credit	Two credits
Man 02: Responsible construction practices				One credit	Two credits
Man 04a: Stakeholder participation		One credit (Building user information)	One credit (Building user information)	One credit (Building user information)	One credit (Building user information)
Man 04b: Stakeholder participation		One credit (Building user information)	One credit (Building user information)	One credit (Building user information)	Three credits (Building user information and Adaptable design)
Hea 01: Visual comfort	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only
Hea 02: Indoor air quality	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only
Hea 04: Water quality	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only
Hea 08: Private space				None	One credit
Ene 01: Reduction of CO_2 emissions				Six credits	Ten credits
Ene 02a: Energy monitoring			One credit (First sub-metering credit)	One credit (First sub-metering credit)	One credit (First sub-metering credit)
Ene 04: Low or zero carbon technologies				One credit	One credit
Wat 01: Water con-sumption			One credit	One credit	Two credits
Wat 02: Water mon-itoring		Criterion 1 only	Criterion 1 only	Criterion 1 only	Criterion 1 only
Mat 03: Responsible Sourcing					Criterion 1 only
Wst 01: Con-struction waste man-agement					One credit
Wst 03a&b: Operational waste				One credit	One credit

Fig. 3: Minimum BREEAM credit requirements for certification

[10] (Portalatin, 2010) page 12

Scope of application: BREEAM fits into a variety of designs and covers different scenarios and building types including renovation and new construction such as;

- Communities
- Courts
- Education
- Health care
- Homes
- Industrial
- International
- Multi-residential
- Offices
- Prisons
- Retail

(Baunetzwissen, 2017)

2.1.2. Leadership in Energy and Environmental Design (LEED)

The Leadership in Energy and Environmental Design is the foremost sustainable rating system in the United States of America most widely used green building rating system in the world. It was formed in 1998 by the USGBC United States green building cooperation and it is well known worldwide. Although having some roots in the BREEAM system, LEED intended to achieve ecological building methods by reducing the negative environmental effects of buildings to ensure energy sufficiency with high quality for more environmentally-friendly and profitable buildings. It is an independent, third-party verification rating system that provides a method of standardization and oversight for environmental performance of various building types. (Richards, 2003) [11]

Available for almost all building, community and home project types, LEED provides a framework to create healthy, highly efficient and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement. (USGBC, 2018) [12]

[11] (Richards, 2003) pg. 1

[12] (LEED is green building, 2018)

LEED avails building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions. This system allows environmental and social factors, including site, water, energy, materials, and indoor air quality, to be weighed side by side with financial metrics in the design process.

SCHEMES AND RATING SYSTEMS

- LEED for *Building Design and Construction BD+C:* Applies to buildings that are being newly constructed or going through a major renovation; includes New Construction, Core & Shell, Schools, Retail, Hospitality, Data Centers, Warehouses & Distribution Centres, and Healthcare.
- LEED for *Operations and Maintenance O+M:* Applies to existing buildings that are undergoing improvement work or little to no construction; includes Existing Buildings, Schools, Retail, Hospitality, Data Centers, and Warehouses & Distribution Centers.
- LEED for *Interior Design and Construction ID+C:* Applies to projects that are a complete interior fit-out; includes Commercial Interiors, Retail and Hospitality.
- LEED for *Neighborhood Development ND:* Applies to new land development projects or redevelopment projects containing residential uses, non-residential uses, or a mix. Projects can be at any stage of the development process, from conceptual planning to construction; includes Plan and Built Project.
- HOMES: Applies to single family homes, low-rise multi-family (one to three stories), or mid-rise multi-family (four to six stories); includes Homes and Multifamily Low rise and Multifamily Midrise.
- CITIES AND COMMUNITIES: Applies to entire cities and sub-sections of a city. Using the Arc performance platform, LEED for Cities projects can measure and manage their city’s water consumption, energy use, waste, transportation and human experience. (USGBC, 2018)[13]

[13] (USGBC, 2018)

Fig. 4: LEED Schemes and rating systems, (USGBC, 2018)

CERTIFICATION LEVELS

The LEED certification is based on a point system, where points are awarded for the fulfilment of individual credits. LEED awards four certification levels and certification is based on an assessment of the completed building. The total points attainable is 110, which are distributed depending on the building type, where the greatest amount of points is given to the energy and atmosphere categories.

- Certified 40 - 49 Points
- Silver 50 - 59 Points
- Gold 60 - 79 Points
- Platinum 80-110 Points

Fig. 5: LEED Certification levels and points, (USGBC, 2018)

Assessment categories[14]

- **Sustainable Sites:** environmental aspects related to the building site are examined with the goal of limiting the construction impact while checking the water outflow.
- **Water efficiency:** aims at the reduction of water consumption and promotion of meteoric water recycle. It is related to the use, management and disposal of water in the buildings.
- **Energy and atmosphere**: deals with the creation and innovative strategies on the improvement of building energy performance, the use of renewable sources and the energy building performance control.
- **Materials and Resources:** In this section, the use of renewable, low cost and maintenance building materials as well as reduction of waste are the major subjects of consideration, in relation to the environmental impact due to transport.
- **Indoor environmental quality:** the satisfaction level of building users is important in this section. This is determined through the indoor air quality control, healthiness, thermal comfort and lighting of the interior spaces in the buildings.
- **Innovation in design:** aims at identifying innovative improvement strategies to improve the sustainability operations in the building construction through the design aspects.
- **Regional priority credits:** much importance is placed on the use of locally made products alongside regional resources during the design, execution and operation of the project. Attempts to encourage design groups to focus on the local characteristics of the environment.
- **Location and transportation:** Credits and granted to projects located on developed sites, where there is ease of access and various means of transportation. Sites with specific restrictions are also taken into consideration.

[14] (USGBC, 2018), (Sadrykia, et al., 2016)

CATEGORIES	**WEIGHTING %**	**CREDITS**	**ISSUES**
Sustainable Sites **SS**	24	26	Construction Activity pollution prevention *(prerequisite 1)* • Site selection • Development Density and Community • Connectivity • Brownfield Redevelopment • Alternative transportation • Site development • Storm water design (Quality control) • Heat Island effect (Non-roof) • Light pollution reduction
Water Efficiency **WE**	9	10	Water Use Reduction *(Prerequisite 1)* • Water efficient landscaping • Innovative waste water technologies • Water use reduction
Energy and Atmosphere **EA**	32	35	Fundamental Commissioning of Building Energy System *(Prerequisite 1)* Minimum Energy Performance *(Prerequisite 2)* Fundamental Refrigerant Management *(Prerequisite 3)*

			• Optimize Energy Performance • On-site Renewable Energy • Enhanced Commissioning • Enhanced Refrigerant Management • Measurement and Verification • Green Power
Materials and Resources MR	13	14	Storage and Collection of Recyclables *(Prerequisite 1)* • Building Reuse • Construction Waste Management • Materials Reuse • Recycled Content • Regional Materials • Rapidly Renewable Materials • Certified Wood
Indoor Environmental Quality IEQ	14	15	Minimum Indoor Air Quality Performance *(Prerequisite 1)* • Environmental Tobacco Smoke (ETS) • Control (Prerequisite 2) • Outdoor Air Delivery Monitoring • Increased Ventilation • Construction Indoor Air Quality • Management Plan • Low-Emitting Materials

			• Indoor Chemical and Pollutant Source • Control • Controllability of Systems • Thermal Comfort—Design • Daylight and Views
Innovation in Design ID	5	6	Innovation in Design LEED Accredited Professional
Regional Priority	3	4	Regional Priority
	100%	110	

Table 2: LEED Scoring and rating system (Sadrykia, et al., 2016)[15]

2.1.3. Deutsche Gesellschaft für Nachaltiges Bauen (DGNB):

DGNB was founded in 2008 by the German Sustainable Building Council in conjunction with the then Federal Ministry of Transport, Building and Urban Development (today: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety). The award for sustainability of buildings in Germany started two years later in January 2009.

Germany's claim to developing its own certificate was to close the gaps in existing systems and introduce further quality criteria that also take German standards and regulations into account. Therefore, DGNB focuses on a wide range of quality criteria ranging from environmental, economic, technical, process and site quality to sociocultural and functional dimensions. “A holistic approach is taken” meaning the system assesses the entire lifecycle of the building. (Knaufinsulation, 2018)[16]

[15] (Sadrykia, et al., 2016)
[16] (Knaufinsulation, 2018)

DGNB is flexible and can be applied to national and international environmental assessment, including 13 different building types and, since 2011, entire urban districts. The evaluation is based on about 40 criteria, subdivided into six categories that are weighted by specific weighting factors. The sum of the points obtained in all the categories provides the overall score for the building.

Fig. 6 The Basic Structure of DGNB System showing the 6 categories and their weights in %

SCHEMES

Since DGNB is a system established in Europe, therefore it is based on European standards. Therefore, it consists of schemes assessed for certification which include;

1. Existing buildings
2. New construction
3. Interiors
4. Districts

These schemes are further broken down to the following types in Germany.

I. New offices
II. Existing offices
III. Residential buildings

IV. Dwellings
V. Healthcare
VI. Education facilities
VII. Hotels
VIII. Retail
IX. Assembly buildings
X. Industrial
XI. Tenant fit-out
XII. New urban districts
XIII. New business districts
XIV. Industrial location

All the schemes are available in german language save 2 which are in English language, used in the international version CORE 14.

Total-Performance Index	Minimum Performance Index	Awards	
from 35 %	— %	Bronze*	DGNB
from 50 %	35 %	Silver	DGNB
from 65 %	50 %	Gold	DGNB
from 80 %	65 %	Platinum	DGNB

*This award is valid only for existing buildings

Fig. 7: DGNB Certification Awards

SCOPE OF APPLICATION: The certificate is designed for buildings of all kinds, from office towers to detached houses to infrastructure such as tunnels and bridges.

CERTIFICATION: Buildings are awarded DGNB certificates in;

- Bronze
- Silver

- Gold
- Platinum[17]

In addition, there is the option of simple precertification in the planning phase.

Project features that lead to a DGNB certification: some features a building must possess to attain the award of DGNB certification are highlighted below;

- Consideration of sustainability criteria in early project phase
- High demands on thermal comfort
- High demands on light quality and daylight utilization
- High requirements for room acoustics
- Good indoor air quality / use of very low-emission building materials
- Use of sustainable materials
- Water saving
- Energetically optimized concept
- Low life cycle costs

CERTIFICATION PROCESS

Builders decide in advance with the certification authorities which quality level they want to achieve. It is necessary to have a certified auditor or planner present during the certification process and for the entire submission process. Documents such as building registration, issuance of a pre-certificate based on specifications signifying intent to earn a certain rating level, documentation of the construction process and issuance of the final certificate must be provided for the certification process. (Portalatin, 2010) *page 24*[18] If all the requirements are met, a pre-certificate - as an advertising opportunity for his building is issued to the client. a continuous inspection takes place during the construction phase. In case of any observed deviation that affects the desired level of certification, a record is made thus must be corrected. If the building meets with the entire procedure and requirements at the final inspection by the DGNB, the certificate will be awarded in addition to a sticker.

(Baunetwissen, 2017)[19]

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[17] (DGNB, 2018)
[18] (Portalatin, 2010) *page 24*
[19] (Baunetwissen, 2017)

ASSESSMENT CATEGORIES:

- Ecological quality
- Economical quality
- Social cultural and functional quality
- Technical quality
- Processes
- Location

The performance of a building is evaluated individually in each category, and weaknesses in one segment cannot be compensated by specific strengths in another segment. To get the certificate, a good grade must be achieved in each subarea.

Table 3: DGNB: Categories Weights and Category Description

CATEGORY	**WEIGHTING FACTOR**	**DESCRIPTION**
Ecological quality	22.5%	Ecological impacts on local and global environment of the building's construction, utilization of renewal resources, waste, water and land use.
Economical quality	22.5%	Life cycle and monetary values
Socio-cultural and functional quality	22.5%	Health, comfort, user satisfaction, cultural backgrounds, functionality and assurance of design quality.
Technical quality	22.5%	Fire and noise protection, quality of the building shell and ease of maintenance.

Process quality	10%	Quality of planning and design, construction process, building use and maintenance and quality of construction activities.
Quality of the location	Rated independently	Transport related topics, risks and image of location.

(Bernardi, et al., 2017)

There are some specific minimum requirements that must be considered, such as the indoor air quality and the Design for all requirements included in the socio-cultural and functional quality criterion, and the legal requirements for fire safety and sound insulation included in the technical quality criterion. It is necessary to achieve a minimum required level in each quality section to obtain the evaluation. (Bernardi, et al., 2017)[20]

[20] (Bernardi, et al., 2017)

Overview of the criteria*

TOPIC	CRITERIA GROUP	CRITERIA NAME
ENVIRONMENTAL QUALITY (ENV)	EFFECTS ON THE GLOBAL AND LOCAL ENVIRONMENT (ENV1)	**ENV1.1** Building life cycle assessment
		ENV1.2 Local environmental impact
		ENV1.3 Sustainable resource extraction
	RESOURCE CONSUMPTION AND WASTE GENERATION (ENV2)	**ENV2.2** Potable water demand and waste water volume
		ENV2.3 Land use
		ENV2.4 Biodiversity at the site
ECONOMIC QUALITY (ECO)	LIFE CYCLE COSTS (ECO1)	**ECO1.1** Life cycle cost
	ECONOMIC DEVELOPMENT (ECO2)	**ECO2.1** Flexibility and adaptability
		ECO2.2 Commercial viability
SOCIOCULTURAL AND FUNCTIONAL QUALITY (SOC)	HEALTH, COMFORT AND USER SATISFACTION (SOC1)	**SOC1.1** Thermal comfort
		SOC1.2 Indoor air quality
		SOC1.3 Acoustic comfort
		SOC1.4 Visual comfort
		SOC1.5 User control
		SOC1.6 Quality of indoor and outdoor spaces
		SOC1.7 Safety and security
	FUNCTIONALITY (SOC2)	**SOC2.1** Design for all
TECHNICAL QUALITY (TEC)	TECHNICAL QUALITY (TEC1)	**TEC1.2** Sound insulation
		TEC1.3 Quality of the building envelope
		TEC1.4 Use and integration of building technology
		TEC1.5 Ease of cleaning building components
		TEC1.6 Ease of recovery and recycling
		TEC1.7 Immissions control
		TEC3.1 Mobility infrastructure

TOPIC	CRITERIA GROUP	CRITERIA NAME
PROCESS QUALITY (PRO)	PLANNING QUALITY (PRO1)	PRO1.1 Comprehensive project brief
		PRO1.4 Sustainability aspects in tender phase
		PRO1.5 Documentation for sustainable management
		PRO1.6 Urban planning and design procedure
	CONSTRUCTION QUALITY ASSURANCE (PRO2)	PRO2.1 Construction site/construction process
		PRO2.2 Quality assurance of the construction
		PRO2.3 Systematic commissioning
		PRO2.4 User communication
		PRO2.5 FM-compliant planning
SITE QUALITY (SITE)	SITE QUALITY (SITE1)	SITE1.1 Local environment
		SITE1.2 Influence on the district
		SITE1.3 Transport access
		SITE1.4 Access to amenities

* All criteria must be fulfilled as part of the certification process. If any of the criteria is not fulfilled, certification cannot be awarded.

Fig. 8: Overview of the Criteria[21]

2.1.4. Haute Qualité Environnementale (HQE)

The Haute Qualité Environnementale (HQE) building certification system was developed by the non-governmental organization Association HQE (ASSOHQE) based in Paris, France in 1994. (HQE, 2017)[22]

This association supports stakeholders, designers, partners, developers, and users during a project's phases and aims to guarantee a high environmental quality of buildings.

Since 2005, the ASSOHQE has been awarded the HQE (Haute Qualité Environnementale) sustainability certificate. The variety of HQE™ certifications allows all players involved in construction and urban planning sectors to emphasize their commitment to sustainable development. It was introduced as a standard for existing and new office and school buildings but could also be applied to single-family homes and

[21] (DGNB, 2018, pp. 26-27)
[22] (HQE, 2017)

larger residential buildings. The French Sustainability Certificate is not compulsory. It is intended to encourage builders and planners to develop buildings with high comfort with low environmental impact. The quality assurance takes place after each phase i.e. commissioning, design and completion - a rating that serves as the basis for the certification. (Baunetwissen, 2017)[23]

CERTIFICATION

HQE covers buildings throughout their life cycle, that is, throughout their design, construction, operation, and renovation.

The certification types available include;

- HQE certification for construction
- HQE certification for Buildings in operation
- HQE certification for Urban planning and development

In France, the HQE certification scheme is operated through 3 different certification bodies:

i. Certivéa (non-residential sector)
ii. Cerqual (collective housing)
iii. Cequami (individual housing).

HQE certification is also available worldwide by Cerway: each HQE scheme can be adapted to meet the specific context of any country. The Cerway has several recognized HQE “Référents” who are professionals in the construction, property management or planning sectors (architects, engineers, town planners, etc.) accredited after training and examination; to ease certification outside of France.

In Brazil, Cerway operates in partnership with the Vanzolini Foundation (Fundaçao Vanzolini) who provides AQUA certification which is a direct translation of HQE.

BENEFITS OF HQE CERTIFICATION

- Lower operating costs
- Energy, water and waste management

[23] (Baunetwissen, 2017)

- Increased asset value and longevity of the building
- Control in terms of quality, costs and deadlines via the management system
- Reduced health risks and sometimes lower insurance costs

(beHQE, 2016) *page 3*[24]

APPLICATION OF CERTIFICATION

HQE Certification for Construction: A comprehensive and reliable assessment of the environmental quality of buildings. This scheme applies to residential, commercial, administrative or service buildings, which are under construction or refurbishment. It recognizes the environmental performance of a building, the quality of life of the users and the environmental management of the project. (beHQE, 2016) *page 4*[25]

HQE Certification for Buildings in Operation**:** is the tool responsible for certifying the sustainable operation of buildings. It promotes continuous progress in the environmental performance of buildings in terms of environment, energy, health and comfort. The Scheme is divided into three certification areas for valuing the engagement of the owner, the manager and the user, independently or jointly. (beHQE, 2016) *page 4*[26]

HQE Certification for Urban planning and development: is the tool for managing urban planning and development projects. It is applied at territorial level, the scheme helps to establish the dialogue between regional planning, urban programming and project design, taking into account sustainable development concerns. Its generic nature makes it adaptable to all territories (urban or rural) of any size and function (residential neighborhood, urban districts, retail activities, tourist complex, etc.). source: (beHQE, 2016) *page 5*[27]

ASSESSMENT CATEGORIES

Energy

Environment

Health

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[24] (Cerway's documentation_Brochure, 2016) *page 3*
[25] (beHQE, 2016) *page 4*
[26] (beHQE, 2016) *page 4*
[27] (beHQE, 2016) *page 5*

Comfort

These four assessment categories mentioned above, structure a set of fourteen targets which are assessed with up to 4 rating stars, indicating the level of achievement in the categories.

The targets include:

1. Site
2. Components
3. Worksite
4. Energy
5. Water
6. Waste
7. Maintenance
8. Hygrothermal comfort
9. Acoustic comfort
10. Visual comfort
11. Olfactory comfort
12. Space comfort
13. Air quality
14. Water quality

Source: (beHQE, 2016) *page 4*[28]

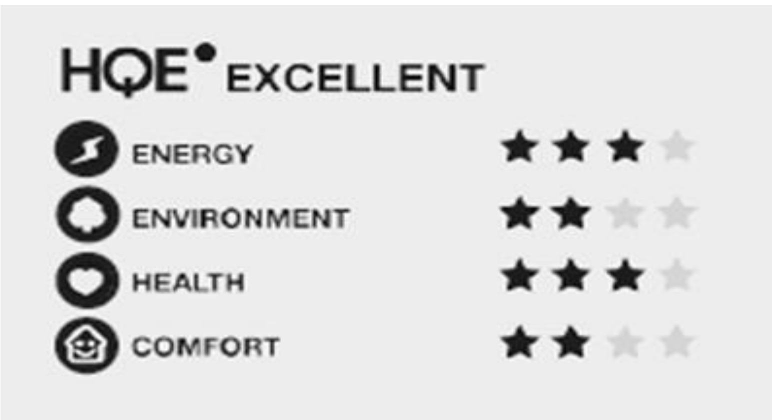

Fig. 9: HQE Categories[29]

Table 4: HQE Categories and Targets

[28] (Cerway's documentation_Brochure, 2016) page 4
[29] (beHQE, 2016)

ENVIRONMENT	ENERGY	COMFORT	HEALTH
• Building's balanced relationship with its immediate environment. • Quality of components • Sustainable worksite -Low site nuisance	• Management of energy • Management of water • Management of waste caused by activities • Management of servicing and maintenance	• Hydrothermal comfort • Acoustic comfort • Visual comfort • Absence of foul smells	• Space quality • Air quality • Water and health quality.

Source: (Portalatin, 2010)[30]

RATINGS

[31]According to the 2016 European sector fact sheet of Policy report on HQE, the new, simplified visualization of the Passport displays the overall performance levels of certified buildings in the fields of energy, environment, health and comfort by applying a ranking of 1-4 stars. The performance ranges from

- Good,
- Very Good,
- Excellent
- Exceptional.

To indicate the global assessment of a building's environmental performance, the stars of all 4 categories are added up to a total of 4 to a maximum of 16 stars.

HQE rating system does not weight each category by a weighting factor, because they are considered to have the same importance throughout the assessment framework.

Table 5: HQE Sustainable Building passport performance scale

1-4 stars	**Good**
5-8 stars	Very good

[30] (Portalatin, 2010)
[31] (EuropeanCommission, 2016)

9-12 stars	Excellent
13-16 stars	Outstanding

CERTIFICATION PROCESS

The HQE certification is a 3-step process:

- Project initiation
- Audits: Audits are third party assessment and verification processes where the HQE criteria required are determined.
- Certification: after submission and careful review of the audit report from initiation to design and completion. (HQE, 2017)[32]

2.2. Relevance of the Rating systems

Since sustainability has become a relevant aspect of our environment today, the need to have a sustainable certified building cannot be underestimated. Although these certificates can be expensive to achieve in terms of costs, time and efforts made, it should be viewed from a long-term investment perspective. The most important factor to be considered is the involvement of the three pillars of sustainable development which are Environment, Economy and sociology into our buildings today. A good sustainable rating system is one which puts all three pillars into consideration.

Consequently, all the rating systems have just one target as their aim and that is sustainability, and this is achieved through resource efficiency (energy, water and materials), reduction of environmental impact, carbon footprint and carbon dioxide emissions elimination. The rating systems also help to improve human health, productivity and efficiency. It is also important in the aspect of developing and stimulating the economy. (Sundus & Altan, 2016)[33]

Furthermore, being certified to international green building standards is crucial for

the long-term success of real estate and businesses. As each certification system provides criteria that gives a holistic view of the quality of the real estate. It also helps to

[32] (HQE, 2017, p. 2)
[33] (Sundus & Altan, 2016)

improve investment costs by saving money, minimize risks and add more value to occupant's quality of living. [34]

2.3. Building Information Modelling

In recent times, the popularity and demand of BIM by the AEC industry has increased considerably making it no longer a new concept but gradually an essential and effective tool. BIM is needed for various reasons within the industry such as facilitating construction projects by design management, offering a digital representation usually in 3D views, and show showing more details of a design or building as a model attached to a database in the construction field. This information can be useful to many of the stakeholders and professionals involved, to ease decision making and refining the process of executing the project. Most BIM software now come with rendering tool, which generates photo realistic images for better interaction with the model and all its views. BIM has helped hugely to decrease the number of hours that was needed to produce design and drawings initially. (Quirk, 2012, p. 2)[35]

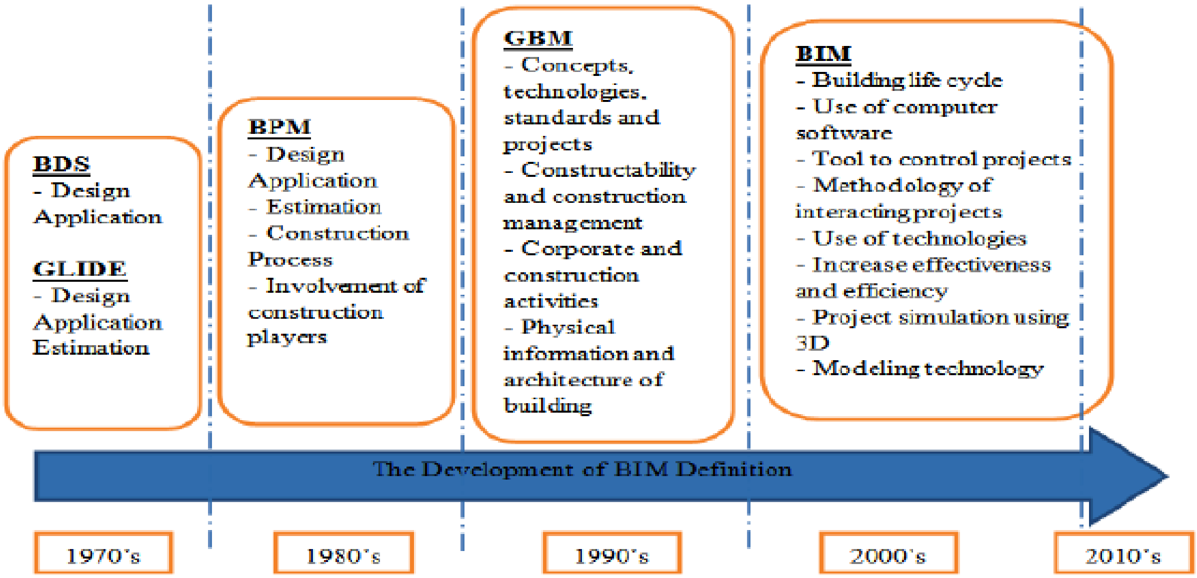

Fig. 10 The development of BIM (Aryani Ahmad Latiffi, et al., 2014)[36]

[34] https://www.tuv-sud.com/uploads/images/1390352048901439950864/tuv-sud-sustainability-rating-systems.pdf
[35] (Quirk, 2012, p. 2)
[36] (Aryani Ahmad Latiffi, et al., 2014)

2.3.1. Introduction to BIM

The concept of Building Information Modelling started in the 1970s by Charles Eastman a trained architect. (Yaman & Bahriye Ilhan, 2016, p. 1)[37] Eastman created one of the first software of BIM known as Building description system (BDS). The software used a graphical user interface, orthographic & perspective views with a sortable database which allows the user to collect information categorically by feature including material type and supplier. (Quirk, 2012)[38] Like every other innovation, there have been constant improvements on the first BIM software mentioned above hence, leading to the creation of various software that exist today for BIM.

Building Information modelling is a set of interrelating strategies, procedures and skills that create a framework to monitor the vital building design and display data in digital layout throughout the building's life-cycle. (Oduyemi & Okoroh, 2016, p. 1)[39] .

There are various definitions and descriptions of BIM by numerous authors and researchers. This shows the importance of the topic of BIM and its various applications today. According to Eastman, BIM can be defined as a modeling technology which relates to processes, production, communication, and analysis of building models. These models are formed for digital representations of the building components, called objects. The objects contain computable graphic and data attributes, and this information can be used for other processes or analysis, such as energy analysis and quantities take-offs. (Eastman, et al., 2011, p. 16)[40]

Since the introduction of BIM into the AEC industry, there has been a lot of changes in the way the industry operates. Generally, BIM has helped to simplify the processes and complex nature of the projects within the industry, enhance communication among professionals and stake holders and encourage collaboration practices. (Krygiel & Bradley Nies, 2008, p. 29)[41]

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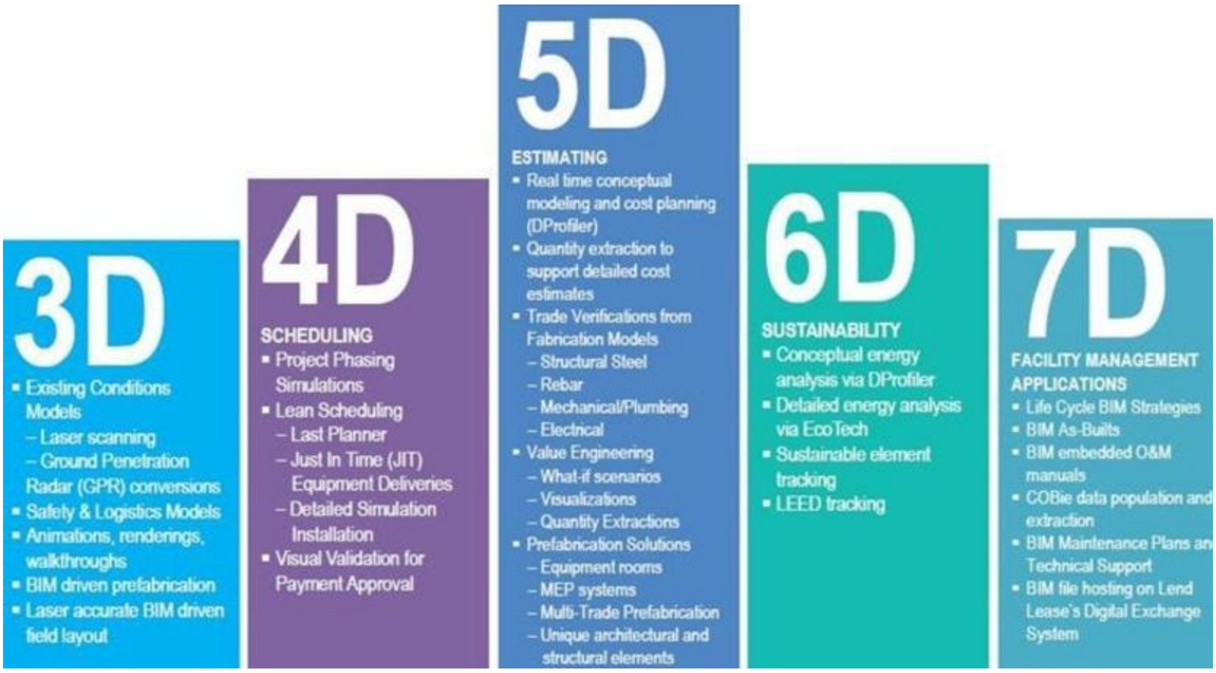
[37] (Yaman & Bahriye Ilhan, 2016, p. 1)
[38] (Quirk, 2012)
[39] (Oduyemi & Okoroh, 2016)
[40] (Eastman, et al., 2011)
[41] (Krygiel & Bradley Nies, 2008, p. 29)



[42]*Fig. 11: Dimensions of BIM*

2.3.2. Features of BIM

i. BIM is more than just a software, it is a new method to design and manage AEC projects at different phases of a building's life cycle. (Krygiel & Bradley Nies, 2008, p. 26)[43]

ii. Provision of object intelligence, data integration and design analysis. This ensures the connection of objects characteristics with other objects and information.

iii. It is embedded with parametric intelligence which makes handling an object easy and less complicated.

iv. BIM technology provides coordinated data which corrects and modifies an object in all views. (Eastman, et al., 2011, p. 19)[44]

v. It also provides satisfied support for project team collaboration. This is achieved through its ability to exchange internal files to different formats, thereby making interoperability between various BIM applications flexible. (Eastman, et al., 2011, p. 18)

[42] https://www.constructiontuts.com/bim-software/
[43] (Krygiel & Bradley Nies, 2008, p. 26)
[44] (Eastman, et al., 2011, p. 19)

2.3.3. BIM Terminology

BIM Tool: refers to applications which produces outcomes that are task-specific. Due to the versatility of BIM, there are various applications existing today with specific tasks or a combination of tasks. (Eastman, et al., 2011) Examples include;

- Model generation for design and feasibility: commonly done by architectural software such as Revit architecture, Structures and MEP, ArchiCAD, Sketchup pro etc,
- Clash detection and 3D design coordination by Solibri model checker, SimpleBIM, Tekla BIMsight, Bentley Navigator.
- Cost estimation by Vico schedule, Autodesk quantity takeoff (QTO), Exactal Cost X, Dprofiler and iRIB Two.
- Building environmental analysis by IDAICE (Indoor climate and energy), Green building studio, Trnsys, Autodesk Ecotect, IES, DesignBuilder, and ArchiWIZ-ARD.
- Structural analysis by Robot, Tekla structures, Matlab, Revit structures, Vector-works, CADduct, Autodesk Civil 3D, Bentley AECOsim.
- Solar analysis by Ecotect

The result of these applications depends on the program of the software, and it may come in form of reports, graphics, tables, rendered 3D models and animations etc.

BIM Platform: refers to software that produces data for multiple uses such as design operations for object creation, editing and modification. Other uses include; clash detection, drawing production and quantity take-off. Platforms also involve parametric rules that allow the automatic combination of the project information. They are generally characterized by similar user interface and interaction style which makes familiarization with different software easy for the user. Some examples include; Autodesk Revit, Tekla Structures, Graphisoft ArchiCAD, and Vector works. (Eastman, et al., 2011, pp. 70-71)[45]

BIM Environment: BIM environment includes all the activities that are needed when organizing and working on a BIM project; this goes beyond the model alone. It includes

[45] (Eastman, et al., 2011, pp. 70-71)

workflow control, work sharing information decisions and platforms integration. The greater the number of platforms used, the greater the level of coordination and data management needed. BIM environment is not an application or software, but it is the data management that form part of using both BIM tools and platforms within a project. Occasionally, the BIM environment can be integrated inside a unique BIM platform. (Eastman, et al., 2011, pp. 70-71)[46]

2.3.4. Merits of BIM

- Encourages collaboration and work flexibility among different stakeholders within the AEC industry and this helps them to have similar approach and views of the project.
- Accuracy in comparison of design options, which leads to enhanced performance.
- Early prediction of risks, conflicts and clashes improves the overall safety of the project before, during and after construction.
- Huge time management strategy without loss of cost and quality, due to earlier decisions regarding design and project delivery.
- Accurate predictions of the design results and clearly communicated to the customer.
- Interface problems are avoided before the construction due to the integration of various works in one 3D model.
- It reduces material waste and improves efficiency by precision in quantity take-offs and accurate cost control system.
- Ease of energy simulation and performance calculation.
- Reduced errors in design and construction documents.
- Improves building design by the integration of sustainable building design.
- Better documentation system is achieved because all the needed data is made compact in a file and updated easily.

[46] (Eastman, et al., 2011, pp. 70-71)

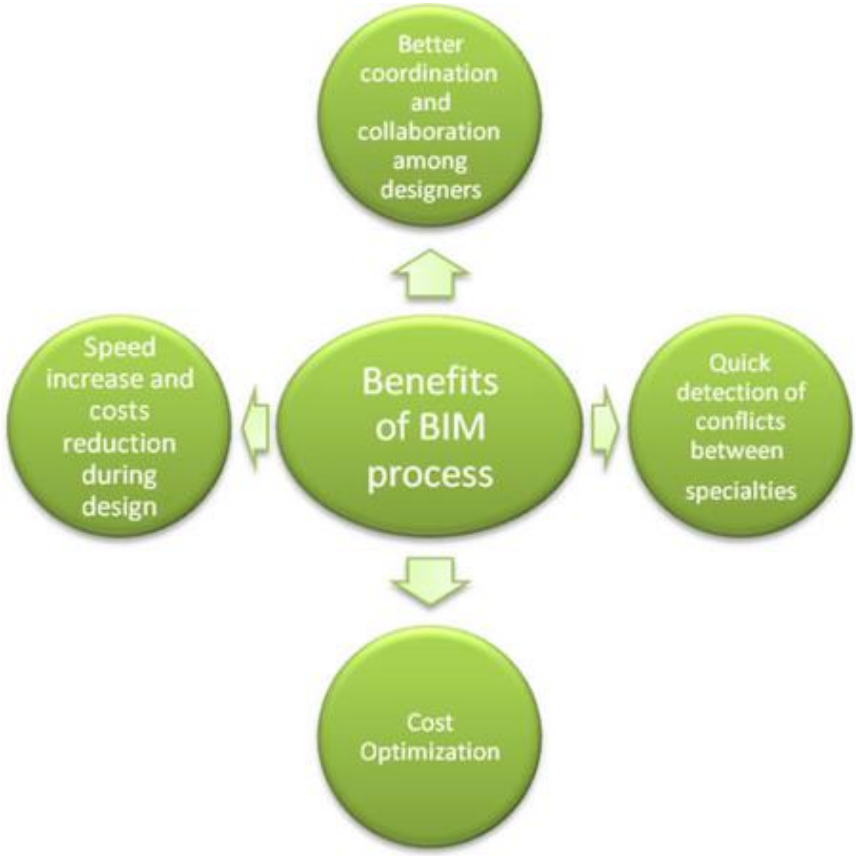


Fig. 12: BIM advantages[47]

2.3.5. Demerits of BIM

Since BIM is still a recent introduction into the AEC industry with global prospects and benefits, time is needed to adopt it as a method of working globally. Hence, the observation of disadvantages arising from the use.

- Adoption of the new trend is not readily accepted by companies and individuals.
- High level of skills required to operate BIM software effectively.
- The cost of training and purchase of original software license is quite high.
- Computer upgrade to more software specific sophisticated computers must be considered by new BIM users.
- Clear method of working and collaboration among team members could be an uphill task.
- Loss of data or information and inefficiency in data management by file exchange from one format to another.

[47] (Associates, 2010-2017)

- Legal ownership to the integrated file by any of the stakeholders could be quite confusing, hence the need to employ a BIM coordinator.

2.3.6. Applications of BIM

There are various uses of BIM in the construction industry. These applications can be further split into three main groups according the Levels of development and phases of a building's life cycle.

- Pre-construction
- Construction
- Post construction

Pre-construction

This stage involves mainly the design and all processes that occur before construction begins. BIM is very useful at this stage for concept development, architectural 3D models, and designs implementation drawings, structural designs, Mechanical and Electrical design, draft scheduling and cost estimation etc. This is the level of development (LOD 100 – LOD 500).

Level of Development	Description
LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Fig. 13: Levels of Development Illustration

Construction stage

BIM is also needed during the construction stage for various uses. Some of the uses include Scheduling (resources, time and materials), cost estimation, clash detection, model checking, energy simulation, team collaboration or work flow and Construction management.

Post-construction

The use of BIM doesn't end right after the construction, it goes on into the facility management stages of the building right into the demolition stage, if there will be any. BIM helps greatly to track renovation and rehabilitation process and progress of the building.

As a step further, the use of BIM relevant to this research is the integration and implementation of the available BIM software to support sustainable design and achievement of green certifications for buildings right from the design stage. The first step toward that is the input of green solutions and consideration right from the design stage into the model.

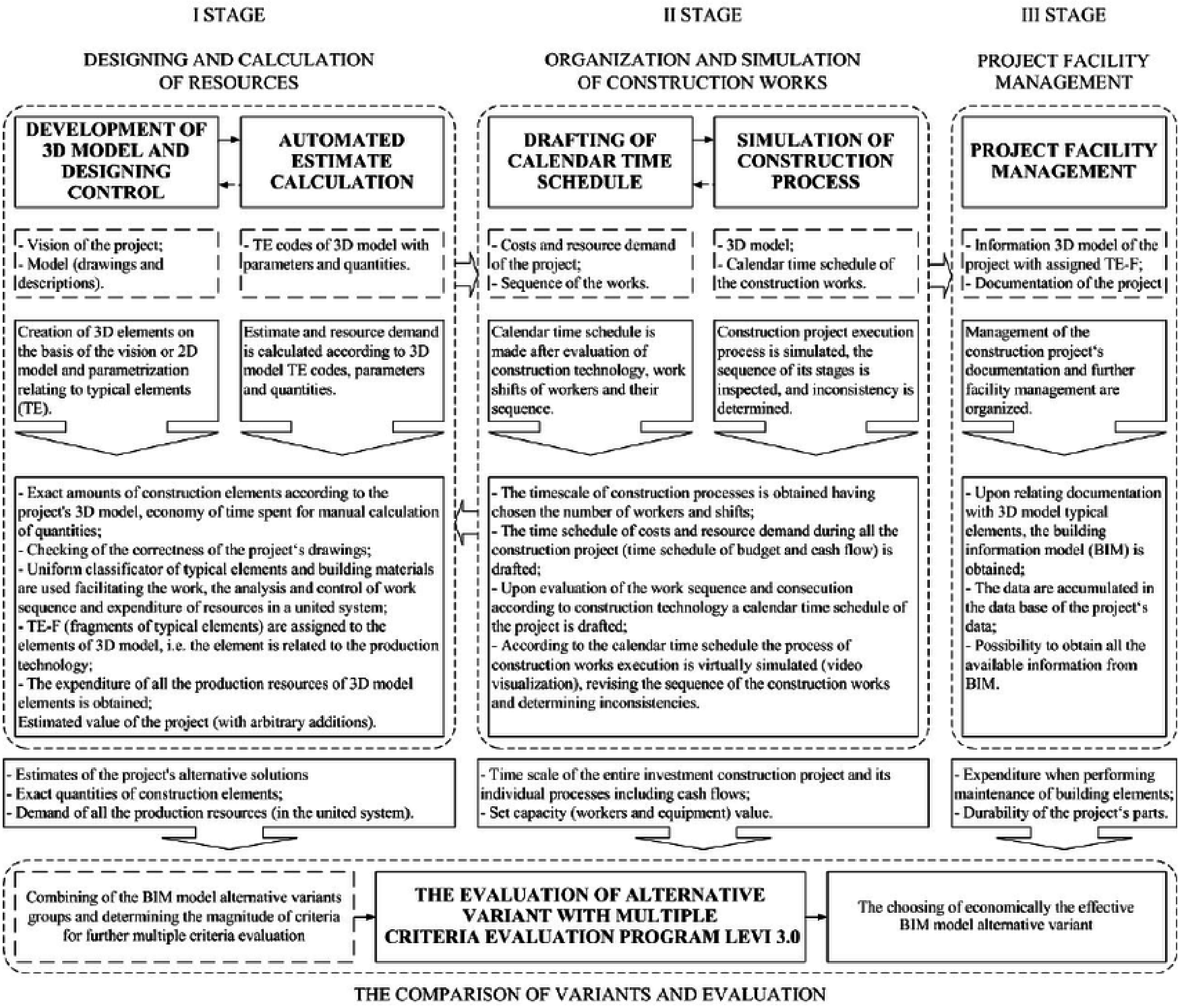


Fig. 14: The Use of BIM[48]

[48] (Popov, et al., 2008)

3.0. BIM AND SUSTAINABILITY

The impact of construction and buildings alike on the deterioration of the environment today is constantly on the increase. This effect has caused a growing awareness of several measures to mitigate these impacts. One popular measure is the Sustainable building rating systems which is becoming more widely accepted today. Many countries around the world have joined the campaign and developed their own rating systems, which are applicable in their home countries and some others widely accepted around the world. (Schlueter & Thessling, 2009) [49]

Due to the development of these rating systems, building can be easily assessed for building performance analysis even before they are built. Studies have shown the importance of early informed decision making before and during the process of design. One of the most convenient ways to achieve this is by using BIM.

BIM has received popularity in recent years. (Wong & Zhou, 2015)[50] Hence, the increased use of BIM within the construction industry to achieve sustainable buildings has led to the development of an integrated design practice that combines BIM technology with sustainable strategies; offering efficient buildings created under a high-performance process. Consequently, BIM has become a common tool used for sustainable building design. This process is known as Green BIM. (Krygiel & Bradley Nies, 2008)[51]

3.1. Green BIM

Green BIM refers to the collaboration of BIM and green building, aiming at obtaining green practices, especially in energy efficiency, into the building lifecycle. It provides an ability to do the simulation for validating the performance of design projects and enables designers to improve their designs and select the optimal one. It combines building projects in the virtual environment and incorporates all associated information including geometry, spatial relationships, geographic information, and quantities and properties of building elements

Green BIM assists in different aspects of sustainable design such as day-lighting analysis, building orientation for reduction of energy costs, building form analysis for

[49] (Schlueter & Thessling, 2009)
[50] (Wong & Zhou, 2015)
[51] (Krygiel & Bradley Nies, 2008)

optimization of the building envelope, energy modeling for the reduction of energy requirements which may result to low costs. reduction on material usage by analysing sustainability of the resources and computing exact quantities required; site and logistics management to reduce waste during construction due to the reduction of errors in the design phase. (Dowsett & Harty, 2013)[52]

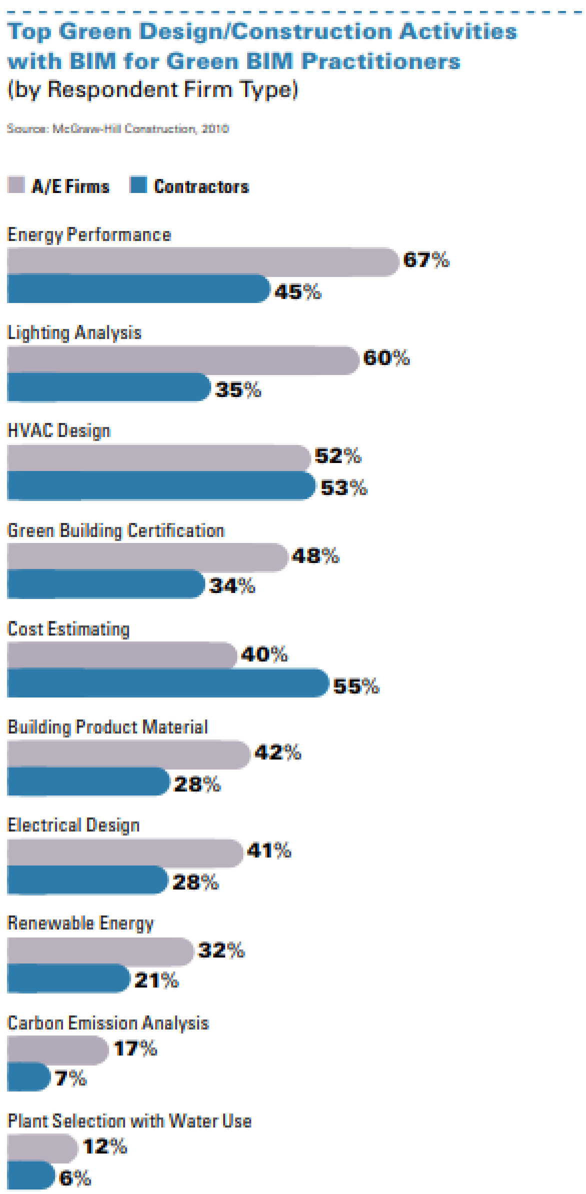
If applied early in the design process, BIM can help to optimize the performance and quality of the buildings in the conceptual phase, BIM is a powerful tool which can be used to evaluate if the building's functionality and sustainable requirements are achievable.

BIM can aid processes like the visualization of the design, its components, and visualization of the building performance, for example, the daylighting performance; the automation between the data avoids mistakes and omissions that can cost time and money; easy extraction of the cost estimations coming from the model information; evaluating the energy efficiency and other sustainability aspects with tools part of the BIM technology or liking the model with other analysis and simulation tools.

In 2010 McGraw-Hill Construction, carried out a survey, among architectural and engineering firms and contractors that use BIM for green practices. The result revealed that it is mainly used to evaluate energy performance, lighting analysis and to design the HVAC systems. All these activities have an important influence on the energy use, operational cost, and Carbon emissions. (McGraw Hill, 2010) [53]

Around 67% of the architectural and engineering firms use BIM for energy performance, 60% for lighting analysis and 52% for HVAC design. The contractors, on the other hand, use BIM more commonly for cost estimation (55%) and for HVAC design (53%). Architectural and Engineering firms including contractors use BIM for green building certifications in percentages of 48% and 34% respectively.

[52] (Dowsett & Harty, 2013)
[53] (McGraw Hill, 2010)



Other uses include: electrical design, renewable energy, carbon emission analysis, and plant selection with water use.

BIM can also provide collaboration tools that improve processes such as the Integrated Project Delivery (IPD). This is a procurement process characterized by effective collaboration, from design to project handover, among owners, designers, and contractors. Hence, early collaboration of multiple design disciplines and stake holders can work on the same file at once, saving time and efforts invested in the traditional coordinating of 2d materials method (Eastman, et al., 2011, p. 9)[54] compared to the short time in coordinating a 3D model.

54 (Eastman, et al., 2011, p. 9)

According to the survey, some of the triggers to the adoption of BIM for sustainability are owner demands and saving costs and time. On the other hand, some of the reasons for the companies not using BIM for sustainability are, that it is easier to do green projects using other existing tools; lack of tools; complicated nature of tools and models; or not having the required functionality. The study shows that the architectural and engineering firms have had an important influence on the propagation of the use of BIM for green design. (McGraw Hill, 2010, pp. 16,23) [55]

The availability of BIM tools is important especially for the architectural and engineering firms. Whereas the contractors the demand of the architectural and engineering firms and the improvement of the construction site safety matter more,
BIM offers many advantages in comparison with the traditional 2D model approach. The objects in a BIM model contain a variety of information that can facilitate diverse environmental performance analysis needed to evaluate or improve the sustainability (Eastman, et al., 2011, p. 161)[56].

3.1.1. Benefits of Green BIM

The introduction of Green BIM is beneficial to the construction industry. Due to the complex nature of the products of the industry, there is an increase in the amount of the information, documentation and level of coordination required for the completion of a project. Consequently, the time and cost for coordination increase. In addition, more building systems result in an increased use of materials during construction and more energy needed during the operational phase, which means more life cycle costs for the building (Krygiel & Bradley Nies, 2008, pp. 29-35) [57]

The bulk of the possibilities of using BIM for sustainability have not yet been fully realized. This can be linked to the fact that it is a very recent concept in the construction industry. However, it will reach its full potential with time and more technology development. The utilization of BIM in the context of sustainability has different advantages which can be grouped into two. One is related to the optimization of the performance

[55] (McGraw Hill, 2010, pp. 16,23)
[56] (Eastman, et al., 2011, p. 161)
[57] (Krygiel & Bradley Nies, 2008, pp. 29-35)

of the building itself. And the other in relation to data management and workflow among teams.

BIM offers tools that can be used for the coordination of the different layers of information in a more accurate and efficient way, this helps with the sustainable design, because it allows the multidisciplinary team to manage all the layers of information needed for sustainability in a more coordinated way. BIM offer tools to perform analysis and simulations to increase the sustainability of each of the systems and the total sustainability of the building. The use of BIM allows changes and adjustments to be made easily.

Green BIM offers a model with adequate data for the existing BIM tools to complete analyses earlier in the design cycle and regularly modify the design options, (AutoDesk, 2012)[58]

All these advantages during the design phase contribute to avoid mistakes during the construction phase. Other possible advantages during construction are better implementation of LEAN construction techniques and synchronization of procurement with the design and construction (Eastman, et al., 2011, pp. 20-26)[59]. All these advantages are related to achieving greater levels of sustainability in the building by improving the performance of the building during its life cycle.

Furthermore, BIM makes it possible to reduce the efforts to extract and prepare the data needed for the analysis models, this data can be directly extracted and prepared from the BIM common model, avoiding the re-modeling process can make the workflow more fluid (Eastman, et al., 2011, p. 224)[60].

From the owner's perspective, the utilization of BIM on a project can provide the potential benefits of the following:

- Increased building value
- Shortening project schedule
- Obtaining reliable and accurate cost estimates
- Program compliance assurance
- Produce market ready facilities

[58] (AutoDesk, 2012)
[59] (Eastman, et al., 2011)
[60] (Eastman, et al., 2011)

- Optimization of facility management and maintenance
- Increased Return on investment for Clients. (Eastman, et al., 2011)

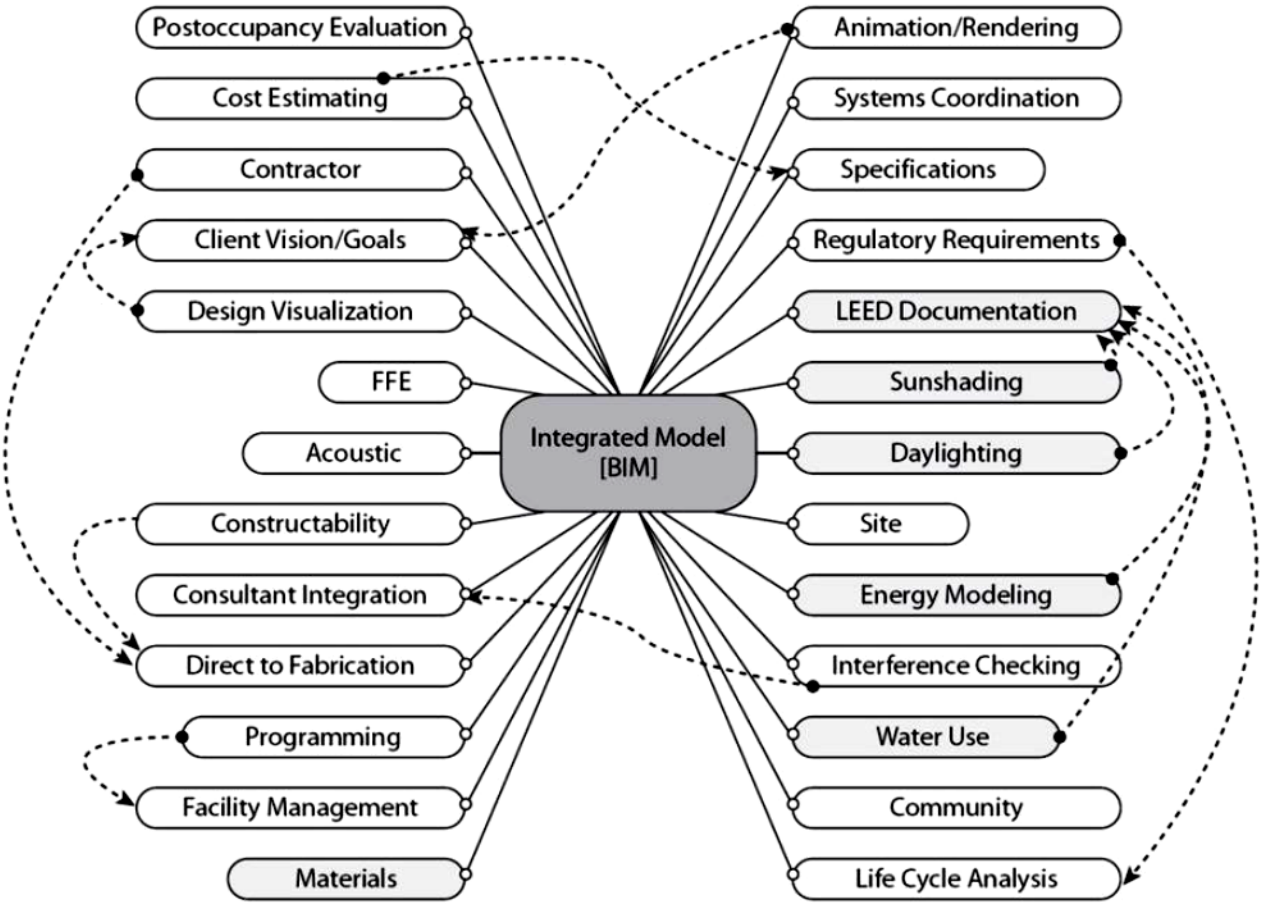


Fig. 15: Integrated BIM model (Krygiel & Bradley Nies, 2008)

3.1.2. Challenges of BIM application in sustainable design

The use of BIM in sustainable design is not the same process as using BIM for architectural or construction design. It requires significant training to be able to successfully perform simulation and analysis of a building. On the other hand, the cost implication of purchasing and licensing as well as training on the use of the software is very high (Bynum, 2010)[61].

The need for computer system upgrade to effectively use the BIM software may be necessary by the stakeholders involved. BIM also requires more effort if applied to a sustainable design project (McGraw Hill, 2010).[62] It requires a meeting with the

[61] (Bynum, 2010)
[62] (McGraw Hill, 2010)

contractor, designers and other stakeholders to create a collaborative model. BIM can disrupt the general procurement and construction process when ordering items that require a long lead time (Bynum, 2010).

3.1.3. Implementation of BIM In Sustainability

The implementation of BIM refers to the expertise level in relation to the application of BIM in sustainability. There are some implementation catalysts that help to forge the application of BIM ahead within the AEC industry. These catalysts can be grouped into various aspects.

3.1.3.1. Government influence

According to the 2013 report by McGraw Hill construction on BIM, *'As BIM adoption continues to grow around the world, governments are promoting its ability to eliminate waste on public projects and even mandating its use as a part of construction sector reform, cost saving efforts and climate change mitigation strategies'.*

One of the leaders in this strategy is the United Kingdom, who implemented a construction strategy that states that BIM will be a key part of the government's procurement of public sector buildings and mandatory use of model-based BIM on all public-sector projects, including delivery of all project and asset information, documentation and data. The idea is to unlock project efficiencies through enabled processes such as early clash detection, building component prefabrication and allow for better sustainable building design and operation.

Other countries like Singapore, United states of America and nations in the European Union and Scandinavia region have also set up different mandatory governmental initiatives, platforms, Task groups and standards at various levels from design, exchange formats, approval even to life cycle management. These decisions by the governments have helped to impress the use and popularity of BIM in the AEC industries both nationally and globally. (McGraw Hill, 2010)[63]

[63] (McGraw Hill, 2010)

3.1.3.2. Owner Influence and User motivation

The influence of the owner usually comes from a standpoint of demanding the best outcomes for the project which include saving costs and time. This is the primary driver for contractors to use BIM on green projects, whereas, AEC firms also place greater importance on how BIM helps them to achieve their sustainability goals. (McGraw Hill, 2010)[64]. On the User side, the motivations are numerous, but the outstanding ones include, time saving strategy, waste reduction and production of high performance facilities. (McGraw Hill, 2010, p. 33)[65]

3.1.3.3. Design Optimization

This involves the inclusion of the best design parameters to meet project requirements and enhance interoperability between stakeholders in the AEC industry. This can be approached in two steps which will be discussed extensively in section 3.2. of this chapter. The two steps involved are;

1. The creation of basic models by using the appropriate BIM software.
2. Export these models to BIM-based analysis tools.

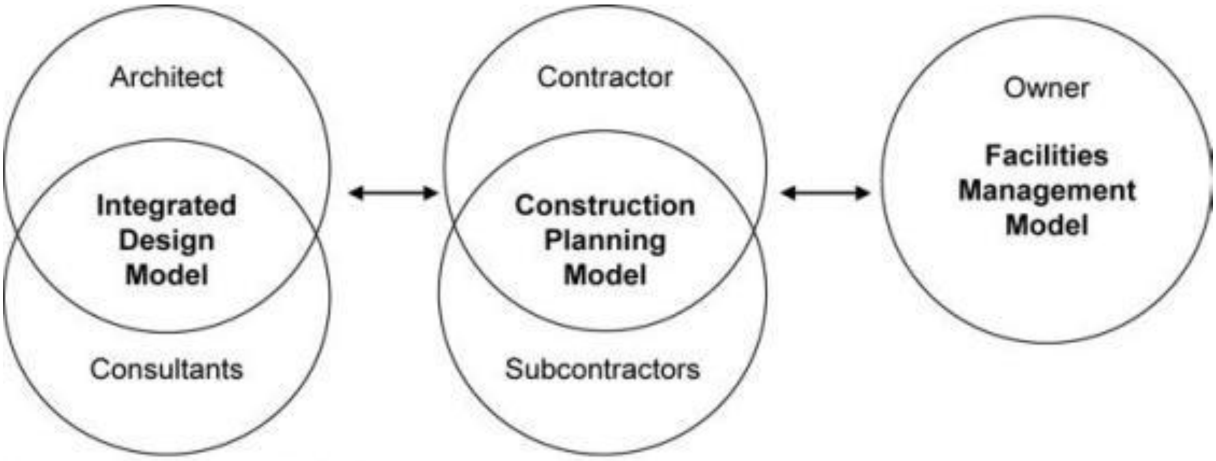
(Kam-din & Qing, 2013, pp. 7-8) [66]

	STEP 1 INHERENT BIM FEATURES	STEP 2 BIM BASED ANALYSIS TOOLS
Software	Revit, ArchiCAD, Bentley, Sketchup etc	Ecotect, IES-VE, Green Building studio (GBS), EnergyPlus, TRACE700, eQUEST, etc
Green Strategies	Building Orientation, Building massing; Load data	Building Load calculations Energy analysis Lighting design Ventilation, Materials.

Table 6: Sustainable Design with BIM[67]

[64] (McGraw Hill, 2010)
[65] (McGraw Hill, 2010)
[66] (Kam-din & Qing, 2013)
[67] (Kam-din & Qing, 2013, p. 8)

After the model has been created in 3D, the next step which is to export it to other analysis tools suitable for sustainability involves the use of Industry foundation classes data model (IFC). This forms the first platform for interoperability between stakeholders and the model. Interoperability among information systems involves the need to transfer data among applications, preventing recreation of data and enabling efficient use of information. It offers potential for considerable savings and financial gain. (Sebastiano, et al., 2017, p. 4)[68]



Source: Krygiel and Nies (2008)

Fig. 16: Design optimization approach review[69]

Another consideration for design optimization is the importance of the inclusion of fourth and fifth dimensions in the file i.e. (time, 4D and time and costs 5D) and other simulation techniques and tools required for sustainable design. This can be easily achieved using BIM specialized software.

3.1.3.4. Energy Analysis: Necessary for the increase in the sustainability of a building in BIM is a clear understanding of the requirements for building energy. Worthy of note in this context is the fact that buildings are responsible for 40% of the world energy consumption and about 36% of greenhouse emissions (GHE). Hence, the importance of upgrading the building's energy performance due to the amount of carbon footprint it possesses.

Due to the uniqueness in the energy requirements for different buildings, it is apparent to consider all energy related items while exploring the energy use in the building

[68] (Sebastiano, et al., 2017)
[69] (Krygiel & Bradley Nies, 2008)

during the design stage. This is where the BIM process and its energy simulation tools and techniques comes into play. (Krygiel & Bradley Nies, 2008)[70]

BIM simplifies the process of energy analysis by integrating various parameters such as air conditioning, water, lighting, ventilation to achieve the best results which are considered as the most suitable for the building, based on design and environmental impact. (Krygiel & Bradley Nies, 2008)[71]

3.2. Software Input

Since the inception of BIM into the AEC industry, companies and software providers have taken up the tasks of optimizing the concept of BIM by creating different software applications with various functions, techniques and outcomes. Most of these outcomes have been adjusted to accommodate sustainable design requirements and features. This is achieved through the upgrade of these software applications to newer versions.

3.2.1. BIM Software applications that support Sustainability.

As mentioned above, sustainable design, analysis, simulation, requirements and features are nowadays integrated into BIM software for enhanced functionality of these software. Some examples of BIM software applications that integrate sustainability requirements within their interface include;

i. Graphisoft ArchiCAD
ii. Autodesk Revit
iii. Autodesk Bentley
iv. Trimble Sketchup Pro
v. Tekla structures
vi. Vector works
vii. Robot
viii. Matlab
ix. AutoCAD MEP / MAGICAD
x. Rhino

[70] (Krygiel & Bradley Nies, 2008)
[71] (Krygiel & Bradley Nies, 2008)

The most common ones Revit and ArchiCAD will be analyzed in this section.

3.2.1.1. **Graphisoft ArchiCAD**

Being one of the pioneer BIM software applications, ArchiCAD was created and released well over thirty years ago primarily for architectural design solutions. (Graphisoft, 2018)[72] Due to the trend in sustainability, the software features have been upgraded into newer versions to keep integrating the requirements of sustainability. The latest version which is ArchiCAD 22 released in May 2018 improves the architectural design and documentation workflow for building façades, construction modeling information management and 2D performance (Graphisoft, 2018)[73]. It also improves the modeling capacities in the BIM environment with an external BIM workflow that uses priority-based connections and smart building materials. As a result of the embedded library, there are varieties of components to choose from and modify if needed to suit your design requirements. This has helped to save time on projects tremendously especially on large projects. ArchiCAD provides add-ons such as Building Explorer, MEP Modeler, and EcoDesigner that simplifies the different building analysis as much as possible and reduces clash detection (Khemlani, 2015)[74] just like most BIM softwares, ArchiCAD offer export to various compatible file extensions such as DWF, DXF and IFC which encourage interoperability among stakeholders. ArchiCAD files can also be rendered into image realistic formats and exported to BMP, PNG, TGA, TIF, JPG. Rendering is made possible by Maxon's latest (R19) CineRender engine. (Graphisoft, 2018)[75]

Some features that support sustainability within the software application include;

A built-in Energy Evaluation functionality: this works with the creation of an energy model and evaluating different aspects of the design energy efficiency such as energy source factors, energy costs, energy efficiency of different building systems, etc.

[72] (Graphisoft, 2018)
[73] (Graphisoft, 2018)
[74] (Khemlani, 2015)
[75] (Graphisoft, 2018)

For the performance of energy simulation; all spaces should to be identified as zones, the model should also include proper surfaces and volume facilities, and proper location factor (Jaric´, et al., 2013, p. 109)[76].

Furthermore, Graphisoft offers an extension for ArchiCAD called EcoDesigner STAR. It allows more options for building performance evaluation including simulation and analysis tools, climate analysis, building energy model calibration, project specific low-energy building solution sets, low-energy demand architectural design, whole building energy efficiency optimization, etc (Graphisoft, 2018) [77]

3.2.1.2. **Autodesk Revit**

Revit is one of the leading applications for BIM, that supports BIM workflow from conceptualization to construction offering features for architectural design, MEP, structural engineering and construction (AutoDesk, 2012)[78]. Although it comes with collaboration abilities, models can be worked on individually by stakeholders and linked through a common RVT extension regardless of their locations, (Bynum, 2010)[79].

Revit offers simulation and analysis options for building performance at a general level, by providing tools for energy analysis at a conceptual level to achieve sustainable practices during the design process.

The energy analysis is cloud based, which makes it easier to do quick comparisons of energy consumption and like cycle costs among other different design options. Revit generates the results of the analysis in a graphic format with visual illustrations to facilitate the result's interpretation. Additionally, the Insight 360 plug-in for Revit offer tools for solar, lighting, heating and cooling analysis and simulation. (AutoDesk)[80]

In the event of a more extensive energy analysis, the model can be exported to Green Building Studio in gbXML format and the design efficiency can be analyzed with Ecotect; while the indoor lighting analysis can be executed with 3ds Max Design. (AutoDesk)[81]

[76] (Jaric´, et al., 2013)
[77] (Graphisoft, 2018)
[78] (AutoDesk, 2012)
[79] (Bynum, 2010)
[80] (AutoDesk)
[81] (AutoDesk)

Interoperability with other software is achievable because Revit is embedded with a variety of exchange interfaces. File extensions like DGN, DWG, DWF, DXF, SAT, and SKP, are supported by Revit for easy import of reference models into the project. To allow participation of every stakeholder of the project all renders, images and videos generated by Revit can be exported to common extension files like JPG, TIF, BMP, PNG, TGA, or AVI. To meet international standard, interoperability with other software manufactured apart from Autodesk is achieved through the building-SMART object-oriented file format, IFC. (Eastman, et al., 2011)[82]

3.2.2. Building analysis software.

Applications and software for Building simulations have existed for a long time. These software mainly use 3D modelling BIM tools such as Revit and ArchiCAD as base for the analysis and simulation of general environmental analysis. BIM software offer compatibility with this tool by different extension and data file types. Some examples of building analysis and simulation tools for sustainable design are listed below.

i. IDA ICE (Indoor climate, and Energy)
ii. Autodesk ECOTECT Analysis 2010
iii. Integrated Environmental solutions Virtual Environment IES-VE
iv. Graphisoft Ecodesigner
v. eQuest (DOE- 2.2)
vi. Trnsys (Transient Systems Simulation Program)
vii. Virtual Environment
viii. Autodesk Green building Studio GBS
ix. Vico schedule
x. Solibri model checker

3.2.2.1. **Transient Systems Simulation Program (TRNSYS)**

Trnsys is one of the pioneer simulation software which has been available for about 40 years. (The University of Wisconsin, 2017)[83] it is an extremely flexible graphically

[82] (Eastman, et al., 2011)
[83] (The University of Wisconsin, 2017)

based software environment used to simulate the behavior of transient systems, (Trnsys, 2018)[84] and helps practitioners and researchers in the energy efficiency community to achieve better results.

While other simulation systems only allow thermal or energy performance simulations, TRNSYS can also be used to model other dynamic processes such as traffic flow and biological processes. The software is made up of two parts: Engine and Library.

The engine, (called the kernel) which reads, interprets and processes the input file, repeatedly solves the system, determines convergence, and plots system variables. **The library of components** that includes solar (thermal and photovoltaic), HVAC, and hydrogen systems, among others. (Trnsys, 2018) Trnsys also includes building simulation (including energy modeling for LEED), solar thermal processes, wind and photovoltaic systems, etc. (Trnsys, 2018) It encourages interoperability by the collaboration feature with other organizations from different countries, including the United States (Thermal Energy System Specialists and the University of Wisconsin- Solar Energy Laboratory), France (Centre Scientifique et Technique du Bâtiment), and Germany (TRANSSOLAR Energietechnik) (Jaric´, et al., 2013, p. 108)[85] .

3.2.2.2. The IDA Indoor Climate and Energy (IDA ICE)

IDA ICE is an indoor climate and energy simulation software, used to calculate the building's energy consumption and air circulation. It was first released in 1998 and is marketed by a Swedish company EQUA Simulation AB with localized packages for Austria, Finland, France, Germany, Sweden and Switzerland (Jaric´, et al., 2013, p. 106)[86]

IDA ICE is a building simulation tool that stands out from the others because it aims at achieving the lowest energy consumption and the highest thermal comfort for building inhabitants by, considering the accurate model of the building, its controllers and systems. It also provides various parameters for user input, such as the heat contribution of the occupants, the sun, and other heating and cooling devices.

[84] (Trnsys, 2018)
[85] (Jaric´, et al., 2013)
[86] (Jaric´, et al., 2013)

It offers a whole-year detailed and dynamic multi-zone simulation application to determine the thermal indoor climate as well as the energy consumption of the entire building (EQUA, 2017)[87]. The User Interface (UI) has three levels; wizard, physical, and mathematical (Kalamees, 2004, p. 2)[88] is intended to facilitate the building and simulation for both simple and advanced cases, and the real-time 3D environment, in combination with comprehensive tables, provides feedback. Different extension packages allow different functions; however, IDA ICE uses IFC as a main and only file format to import CAD files including parameters. Other file formats are 2D and vector files, which have neither additional parameters of the elements, nor three dimensional elements. This prevents the ability to consider other industry standard file formats like gbXML. (EQUA, 2017)[89] The ASHRAE 90.1-extension helps users to follow the Building Performance Rating Method, which is used in green building rating systems like LEED and BREEAM. (Carolis, 2015)[90]

3.2.2.3. **Autodesk Ecotect Analysis**

Autodesk Ecotect analysis sustainable design analysis software is a comprehensive concept-to-detail sustainable building design tool, offering a range of simulations that can improve the performance of the design process from early stages of the project in the development of sustainable predictions for the whole lifecycle of the building (Marval, 2016) [91].The interactive 3D platform allows for multiple sustainable design tools to provide for simulations and analysis. It provides functions for whole building analysis based on solar energy, daylighting, acoustics, and thermal properties. Ecotect possesses the ability to build the mass of a structure within its interface, to determine specific criteria such as optimal location, shape, and building orientation to create more sustainable constructs. Simulations and analysis is processed on the platform of Green Building Studio web-based technology using the gbXML exchange format. In addition to whole building analysis, Ecotect provides tools for the analysis of Natural ventilation, Daylighting, wind energy, solar radiation, LEED daylighting credit potential,

[87] (EQUA, 2017)
[88] (Kalamees, 2004)
[89] (EQUA, 2017)
[90] (Carolis, 2015)
[91] (Marval, 2016)

Thermal performance, Visual impact, Acoustic analysis, Water use and cost estimates, ENERGY STAR scoring and a host of others. (Autodesk, 2005)[92]

There is possibility for a seamless translation of information using gbXML and IFC file extensions.

3.2.2.4. **Green Building Studio (GBS)** is a cloud-based energy analysis tool which performs energy, water, thermal, lighting, value, cost and carbon emission analysis of buildings at the early stages of the design process. (Jaric´, et al., 2013, p. 102)[93] Green Building Studio software is designed to work together with BIM applications especially Revit as a plug-in; Hence, allowing easy exchange of data between them.

3.2.3. Exchange formats and Interoperability

Due to the complexity and fragmented nature of the construction industry, the quality of communication among the different stakeholders need to be carefully planned and constantly upgraded to achieve effective BIM practices in a project. The building process will be more improved and standardized if the data is satisfactorily made available to all.

Interoperability involves data transfer among applications, preventing repetition of data enabling efficient use of information with considerable savings prospects.

Interoperability comes with a series of exchange formats with easy transfer of information regardless of the location. Listed below are some common file exchange formats that are widely employed by BIM and simulation softwares;

i. DWG
ii. DXF (Design exchange format)
iii. ifcXML
iv. IFC (industry foundation classes)
v. gbXML (Green building extensive markup language)
vi. CIS/2 (CIMsteel integration standard version 2)
vii. IGES (Initial graphic exchange specification)

[92] (Autodesk, 2005)
[93] (Jaric´, et al., 2013)

The most common exchange formats for interoperability in the context of building sustainability are the IFC and the gbXML (Green Building Extensive Markup Language). These all the easy transference of data of BIM model files from Revit or ArchiCAD, to analysis and simulation software applications. Since each analysis is unique in terms of the data extracted, these exchange formats serve as basis for most of the software applications and no different exchange format can be created. (Eastman, et al., 2011, p. 226)[94]

3.2.3.1. **The Industry Foundation Classes (IFC)**

IFC is a public, nonproprietary data model for buildings; it is also a schema that uses an EXPRESS schema language that has been developed for the ISO STEP (Standard for the Exchange Product Model Data).

IFC specifies how information is to be exchanged, being a standardized neutral data format to describe, exchange and share information. It is an object-oriented data model of buildings, specifying physical items or abstract ideas and their relationships (decomposing, assigning, connecting, associating, and defining).

3.2.3.2. **gbXML**

The Green Building Extensive Markup Language (gbXML) is a recent development created to focus on the green building and energy efficient buildings. It uses an XML scheme language, that was developed for Green Building Studio Inc. It allows the exchange of information between BIM models and other building analysis software; and is especially developed to transfer data needed for energy analysis of the envelope, zones, and mechanical equipment simulation. gbXML is characterized by the following features.

i. Works in cooperation with IFC files to aid the energy analysis software.
ii. It is tightly with a model whose energy parameters are well defined in Revit.
iii. It consists of specific data about energy use in a building e.g. weather data, energy usage profiles and geometric model.

[94] (Eastman, et al., 2011)

iv. The structure of the file is optimized to contain as much information about the energy of the building as possible.

gbXML is famous for information exchange between Web applications, however, some schemes have been developed from it for the AEC industry area, like the gbXML. (Eastman, et al., 2011)[95]. Product vendors like Autodesk, Graphisoft, and Bentley broadly use this format.

One of the differences between IFC and gbXML is that IFC is building geometry and model metadata focused while gbXML is concerned about the features used for energy analysis. The IFC includes more data about the building including geometric characteristics than gbXML, but without a specific focus in the energy analysis model. IFC is more suited for exchanging information between different BIM authoring tools and gbXML in exchanging between BIM authoring and analysis software. (Green Building XML (gbXML) (Marval, 2016) [96].

Due to the possibility of the existence of more energy analysis software applications which have gbXML embedded as an exchange format, it becomes imperative to scrutinize the workflow among stakeholders to ensure compatibility and enhance interoperability.

3.3. BIM and green building rating systems.

Due to the existence of various software applications, total integration of BIM and rating systems is almost an abstract thing. One possibility of achieving this is by the development of interoperable software environments, that utilize open standard formats like IFC and the consideration of the Level of Development (LOD) and the Model View Definition (MVD) (Wu & Issa, 2012)[97].

3.3.1. Integration of BIM and Green building rating systems.

Integration models between BIM and different rating systems, that optimize the certification process are an option that can be evaluated. This could inspire the AEC industry to perform more integrated processes. When BIM is used to store information for rating

[95] (Eastman, et al., 2011)
[96] (Marval, 2016)
[97] (Wu & Issa, 2012)

systems certification processes it allows the collection of different classes of data such as; model data, field data and inventory data which are all crucial in obtaining certification. A BIM model usually referred to as the model data, can be used to extract information of quantities, schedules etc. This should ideally allow easy access to the BIM model by authorized team and ensure the possibility of exchange of information between software platforms. The field data refers to the construction model as an evolution of the design model; where the project team members fill in all information of the evolution of the construction site. The inventory data refers to equipment and materials. (Wu & Issa, pp. 377-378)[98].

3.3.2. Certification process

BIM provides all needed information for different aspect of sustainable design. The amount of detail it provides can be analyzed for the green building certification. A change or adjustment in the model of the building will result in a corresponding update of the building analysis. This allows for convenience in making green certification with BIM compared to application of conventional method; where a change to the model may result to reassessment of the drawing. Hence, a deficiency in time and cost effectiveness.

3.3.3. Green certifications supported by BIM

To attain the award of green building certification for buildings, designers should conduct different sustainability analysis based on a variety of aspects like resource efficiency, materials, building form, systems, etc. Since BIM allows multidisciplinary information to be handled in a unique model; it can help to facilitate the process of performing the analysis and simulations by providing more accuracy and efficiency in the production and evaluation of the building information. (Villegas, 2016)

Commonly the elaboration of the BIM model or documentation for the project, and the certification are done as separate and independent processes. Consequently, there is no correspondence between the processes, this results in needing extra time to compile all the information required for certification. Hence, making it more difficult for the

[98] (Wu & Issa, 2012)

connections between the design or planning decisions and results of credit counting to be visible.

4.0. BODY/FINDINGS

4.1. Research methodology

The method adopted for this research was collection of data both from primary and secondary sources. Since the focus of the research is about rating systems, majority of the data used was retrieved directly from the official technical manuals for rating schemes. These data were mostly found in the official homepages of the certification organizations and from previous scientific research papers.

Since the Sustainability and BIM are fast becoming topics of global interest, most of the literature which was mainly about the selected four sustainable rating systems and a concise examination of Green BIM were easily accessible from books, journals and conference proceedings pertaining to the issue.

The sustainable rating systems examined during this research were selected after meeting the following criteria;

- Wide spread adoption with more than 500 certified projects
- Consolidated development state with more than 5 years of service
- Widely applicable in European countries.
- With an exclusive focus on buildings

In addition, the comparison between the selected certifications was carried out. This comparison consists of examining the similarities and differences between these rating systems, their requirements and categories. A result was drawn from the tables of comparison and applied into the reference model case study.

The reference model of an existing building which is already awarded with LEED platinum certification was used for the purpose of this research. BIM application which played a major role in supporting the award of this certification was extensively used. The case study is Haus 12 on the EUREF campus in Berlin, Germany.

4.2. **Analysis of the selected certifications**

As earlier stated in the literature review and in section 4.1. above, the selected rating systems adopted for this research are;

i. BREEAM
ii. LEED
iii. DGNB
iv. HQE

These systems were carefully picked after fulfilling the criteria listed in section 4.1. of this research. One common feature these four-rating systems share is that they are widely adopted by many countries in Europe. As stated in the Smart market report 2010 by Mc Graw Hill construction, although BIM is still not yet fully adopted by design and planning companies in most European countries (McGraw Hill, 2010)[99], the topic of sustainable development is no longer news or an issue of negotiation as it has been established, adopted and currently widely practiced in all nations of the EU and other parts of the world.

BREEAM which has its roots in the European continent is the pioneer sustainable rating system in the world with over 500, 000 certified buildings and more than 2,000,000 registered buildings scattered around the world since inception. (BRE, 2018) Section 2.1.1. of this research contains more information on this rating system.

LEED although not established in Europe, is the most common certification system existing today. LEED is widely used by most building owners possibly because of its flexibility and broad range of categories and types which covers almost all types of construction projects today. Refer to section 2.1.2. of this research for more information on LEED.

DGNB is a German based certification system originating from the BREEAM system. The DNGB was launched in 2009 by Federal Ministry of Transport in collaboration with Building and Urban Affairs with the aim of promoting building sustainability in Germany and developing a German certificate for sustainable buildings. (Bernardi, et al.,

[99] (McGraw Hill, 2010)

2017)[100] A more detailed information on DGNB can be found in section 2.1.3. of this research.

HQE was developed in the year 1994 in France and gaining popularity around the world through Cerway; an organisation set up to support international evaluations. covers buildings throughout their life cycle, that is, throughout their design, construction, operation, and renovation. (Bernardi, et al., 2017)[101] More details can be found in section 2.1.4. of this research.

4.3. **The comparison sheet/table**

This section is aimed at carrying out a concise comparison of the selected rating systems analysed in this research. The comparison is based on the following points;

1. General features of the rating systems
2. Similarities of the rating systems
3. Differences of the rating systems

[100] (Bernardi, et al., 2017, p. 9)
[101] (Bernardi, et al., 2017, p. 10)

4.3.1. **Rating systems description and general features.**

Table 7 Comparison- Rating systems description and General features

	BREEAM	**LEED**	**HQE**	**DGNB**
Year of Establishment and Location	1990, UK.	1998, USA	1994, France	2007, Germany
Certification Body	BRE	USGBC	CERWAY, Certivèa, Cer-qual, Cèquami	DGNB
Number of certified units	565,299[102]	>47061[103]	1793	>2500 by Dec 2017[104]
Certification phases	- Planning - Project completion	- Planning - Construction - Project completion	- Planning - Construction - Project completion	

102 (BRE, 2018)
103 https://www.usgbc.org/articles/usgbc-statistics
104 DGNB certificate: https://www.dgnb-system.de/en/projects/

Building types	All building types	Consists of different schemes which apply to various types of buildings	Residential properties, office and administrative properties, public buildings and educational buildings.[105]	New construction such as; Residential properties, Offices • Retail, Hotels, Industry and Health properties Specified districts new construction City districts such as Industrial sites and commercial districts Existing buildings • Offices and administrative properties
Ratings	Pass / Good / Very good / Excellent / Outstanding	Certified/ Silver/ Gold / Platinum	Pass / Good / Very Good / Excellent / Exceptional	Gold / Silver / Bronze
Number of categories	10	8	4	6
Weightings	110 (Applied to each category)	100% (Applied to each category)	N/A	100% (Applied to each category)

[105] (RICS, 2013)

No of Schemes	5	6	3	4[106]
Schemes	• Communities for master planning • Infrastructure • New construction • In-use • Refurbishment and fit-out	• Building Design and Construction BD+C • Operations and Maintenance O+M • Interior Design and Construction ID+C • Neighbourhood Development ND • Cities and communities • Homes	• HQE certification for construction • HQE certification for Buildings in operation • HQE certification for Urban planning and development	• Existing buildings • New construction • Interiors • Districts
Third party valuation	BRE Global	GBCI	CERWAY	DGNB
Update process	Annually	As required	Annually[107]	
International versions	Yes	Yes	Yes	Yes

106 https://www.dgnb-system.de/en/schemes/scheme-overview/
107 (RICS, 2013)

	Non-domestic refurbishment In-use New construction: buildings	LEED v3.0 for new construction & major renovations LEED for homes LEED for core and shell • LEED for existing buildings: operations & maintenance • LEED for commercial interiors • LEED for schools • LEED for retail • LEED for healthcare • LEED for neighbourhood development (in pilot stage)	• Non-residential building in operation • Infrastructures • Habitat and environment • Non-residential building under construction • Residential building under construction • Management system for urban planning projects	Core 14
National adaptations	United Kingdom, USA, Germany, Netherlands, Norway, Spain, Sweden, Austria, Switzerland, Luxembourg	Argentina, Brazil, Canada, India, Italy	Belgium, Luxembourgh, Germany, Italy, Morrocco, UK, Brazil	Austria, Bulgaria, China Denmark, Germany Switzerland, Thailand

4.3.2. **Assessment categories, weightings and credits**

Table 8 Comparison- Assessment criteria, weightings and credits

	BREEAM	Weight	Cred-its	**LEED**			**HQE**		**DGNB**	
ASSESSMENT CATEGORIES	Management	20	12	Indoor environmental quality	14	15	Site		1. Ecological quality	22.5%
	Health & wellbeing	15	18	Innovation in design	5	6	Components		2. Economical quality	22.5%
	Energy	19	22	Regional priority credits	3	4	Worksite		3. Social cultural and functional quality	22.5%
	Transport	10	10	Sustainable sites	24	26	Energy			
	Water	5	8	Water Efficiency	9	10	Water		4. Technical quality	22.5%
	Materials	13.5	11	Energy & Atmosphere	32	35	Waste		5. Processes	10%
	Waste	7.5	6	Material resources	13	14	Maintenance		6. Location	-
	Land use	10	10				Hygro-thermal comfort			
	Pollution	13	8				Acoustic comfort			
	Innovation	10	10				Visual comfort			
							Olfactory comfort			
							Space comfort			
							Air quality			
							Water quality			

4.3.3. **Similarities**

	PARAMETERS	BREEAM	LEED	HQE	DGNB
SCHEMES	• New Buildings	✓	✓	✓	✓
	• Existing Buildings	✓	✓	✓	✓
	• Interiors	✓	✓	✓	✓
	• Urban Planning Projects	✓	✓	✓	✓
BUILDING TYPES	• Residential Buildings	✓	✓	✓	✓
	• Office Buildings	✓	✓	✓	✓
	• Commercial Buildings	✓	✓	✓	✓
	• Educational buildings	✓	✓	✓	✓
	• Industrial buildings	✓	X	✓	✓
	• Other type of buildings	✓	✓	✓	✓
	• Urban planning	✓	✓	✓	✓
BUILDING LIFE CY-CLE PHASES	• Predesign and Design	✓	X	✓	✓
	• Construction	✓	✓	✓	✓
	• Post-construction	✓	✓	✓	✓
	• Use/Maintenance	✓	✓	✓	✓

Table 9 Comparison-Similarities between Rating systems

4.3.4. **ATTRIBUTES AND RATINGS**

Table 10 Comparison- Attributes and Ratings

SCOPES	RATING SYSTEMS	BREEAM	LEED	HQE	DGNB
Energy	Energy performance	✓	✓	✓	✓
	Renewable technologies	✓	✓	✓	✓
	HVAC	✓	✓	✓	✓
	Lighting	✓	✓		✓
	Reduction of Energy Use and Emissions	✓	✓		
Indoor Environmental Quality	Olfactory comfort	✓	✓	✓	✓
	Visual comfort	✓	✓	✓	✓
	Thermal comfort	✓	✓	✓	✓
	Acoustic comfort	✓	✓	✓	✓
	Air quality		✓	✓	✓
Innovation	Innovation	✓	✓	✓	✓
Management	Management	✓	✓	✓	✓
	Building Information and Users Guide	✓	✓		✓
	Economic assessment	✓			✓
	Integrative Design process		✓		

	Materials Reuse	✓	✓		✓
	Environmental product declaration		✓		
Materials and Resources	Materials	✓	✓	✓	✓
	Water	✓	✓	✓	✓
	Land Use	✓	✓	✓	✓
Pollution and Waste	Noise pollution	✓	✓	✓	✓
	Light pollution		✓	✓	
	Waste Water Management	✓	✓	✓	✓
	Solid Waste management	✓	✓	✓	✓
Resistance against natural disasters	Earthquake prevention	✓		✓	✓
	Resistance against Natural disasters		✓	✓	✓
Site quality	Outdoor Amenities and facilities	✓	✓	✓	✓
	Transport		✓	✓	✓
	Urban planning	✓	✓	✓	✓
	Ecology and Environmental quality	✓	✓	✓	✓

4.3.5. COMPARISON OF RATING SYSTEMS (BUILDING AND CONSTRUCTION)

Table 11: Comparison - Characteristics of the rating systems[108]

	BREEAM	LEED	HQE	DGNB
APPROACH	Multiple-choice certification	Multiple choice certification	Overall quality approach	Holistic perspective on sustainability
Items and requirements	Very comprehensive Numerous concerns	Targets the essential	Very comprehensive Prevalence of prevalence quality	Intricately selected numerous items
Characteristics	Prescriptive aspect often too pronounced Good adaptation to the local normative context Not very interactive audit process Adaptable to all types of projects, including those with lower energy objectives	Widely used internationally Preponderance of energy and materials aspects Oriented towards preparation for operation US standards very present. Tending to die out with V4	Flexibility The individual is a central component of the process. Very adaptable to the project's environment: heavy contextualisation Verification "in person", with an independent third party facilitating dialogue Project management integrated into the system fostering IDP26	Focus is on sustainability aspects Functional requirements for building performance help to encourage innovation. Unique assessment of every project.[109]

[108] (GBC, 2015)
[109] (Hristova, 2016, pp. 31-32)

Table 12: Comparison- Environmental issues[110]

PARAMETERS	BREEAM	LEED	HQE	DGNB
ENERGY				
Budget work	Indirect recognition	Indirect recognition	Technical note biocli-matic principles to be provided	
Limitation of power con-sumption	Yes	Yes	Yes	Yes
Use of renewable energies	Yes	Yes	Yes	Yes
Energy monitoring during operation	Yes	Yes	No	Yes
Minimum level	From the 'Excellent' level	Prerequisite: minimum 5% improvement	Prerequisite: minimum 10% improvement	
MATERIALS AND EQUIPMENT				
Reuse of a part of an exist-ing building	Indirect recognition	YES	Indirect recognition	

[110] (GBC, 2015, pp. 21-22)

Disassembly capability for recycling of materials at end of life	NO	YES	YES	YES
Environmental impact/over-all cost	Analysis of overall cost according to ISO 15686-5 LCA study recognised	Environmental impact study of the complete building, data in compliance with ISO 14044	Environmental impact study by product family, according to DEP	
Health impact	Choice of low-emission materials/low TVOC and formaldehyde content + Measurement of air quality upon delivery and compliance with thresholds			
Responsible source	Environmental policy (ISO 14001, FSC)	Specific credit	FSC wood	
TRANSPORTATION				
Clean vehicles	3% of parking spaces for electric vehicles (including ecological electricity supply)	3% to 5% of parking spaces reserved for “clean vehicles”	10% of parking spaces for electric vehicles	
Number of parking spaces	If possible 1 space per 3 users (or fewer)	Quantitative approach	Qualitative approach to sharing with other buildings	

Public transport	Calculation of a transport index using a special tool	Number of daily services less than 400/800 m	Number of routes less than 200/600m from the entrance + frequency	
MAINTENANCE OF THE BUILDING AND EQUIPMENT				
Access to the building	No	No	Accessibility study	
Access to finishing, protection elements	Protection of spaces sensitive to traffic	No	Ease of upkeep Adaptable	
Technical rooms	No	No	Easy to access	
Technical equipment	No	No	Easy to access; Adaptable	
Ductwork	No	No	Easy to access; Adaptable	
Monitoring and metering	Yes			
Comfort control	Yes			
Deployment	Yes			

All the rating systems are designed to recognise and consider environmentally friendly objectives and parameters, due to the direct impact it has on building occupants. Some examples include, mode of transport, private vehicles parking space limitations, life cycle analysis and energy consumption calculations.

5.0. THE REFERENCE MODEL

The study of sustainable rating systems and BIM will be incomplete without the analysis of a reference model. The aim of using a case study in this context is to examine a building located in Europe which possess the highest certification of any of the analysed ratings systems in this research. A recently constructed building will be suitable for this study because of the level of BIM input in the design, construction and award of certificate for the building.

5.1. Case study - EUREF HAUS 12 - 13

The case study as earlier mentioned is an existing building that adopted BIM throughout the building, design and construction process and even during the operating stage for continuous energy analysis. The reference model is located in the Europäisches Energieforum (European Energy forum; EUREF) Campus. It is also the first building to be awarded the LEED Platinum certificate in Berlin, Germany.

Fig. 17 Haus 12-13, EUREF Campus[111]

[111] (EUREF, 2018)

▪ **ADDRESS**	✦ Torgauer Straße 12-15 in Berlin Schöneberg; Berlin Germany.
▪ **TYPE**	▪ Office building
▪ **AREA COVERED**	▪ 15,200m²
▪ **YEAR OF CONSTRUCTION**	▪ 2013
▪ **CERTIFICATE**	▪ LEED Platinum 2014
▪ **INVESTMENT COSTS**	▪ Circa €6.500000[112]

Table 13 General information of the Haus 7, EUREF Campus[113]

Fig. 18 Site plan of the EUREF Campus, Berlin

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[112] (BLS Energieplan, 2015)

[113] https://www.euref.de/de/vermietung-gebaeude/architektur-und-bauen/

5.1.0. Building Information

The EUREF campus is a reference environment for sustainable development in Berlin. It is considered as a model example of a smart city intended for work, research, education and dwelling (BLS Energieplan, 2015)[114]. Currently there are another 20,000 square meters under construction on the site around the Schöneberger Gasometer, which will receive LEED certification. (EUREF, 2018)

However, the "EUREF-Campus Haus 12-13" which was completed in 2013, was officially awarded the internationally recognized LEED Platinum Certificate in the category "Building Design and Construction - Core and Shell Development" on 17 July 2014. Making it, the first LEED Platinum certified building in Berlin to receive this US Green Building Council award in this category.

Haus 12-13 was designed with an emphasis on energy efficiency, sustainability and functionality. (BLS Energieplan, 2015) The LEED Platinum-certified Green Building exemplifies the high office quality on the EUREF campus and features energy-efficient insulation, triple-glazed windows with integrated sunshades and smart facades. The office lighting is automatically regulated according to presence and daylight. The building materials were carefully selected from the greatest possible health and environmental compatibility. An intelligent building and energy management system developed by Schneider Electric - also a tenant on the EUREF Campus 12-13 - controls the energy and heat supply of the fully let new building, ensuring optimal energy use with minimal consumption.

The building is currently fully occupied by tenants such as the French Schneider Electric, BLS Energieplan GmbH, ÖKOTEC Energiemanagement GmbH, Taxellenz, Arcadis, Hubject, EICT, Alphabet, WZB and EUREF AG.[115]

[114] (BLS Energieplan, 2015)
[115] (EUREF, 2018)

Fig. 19 Haus 12-13 View from the access road

5.1.1. Architectural description

The building plot is located on the EUREF campus in Torgauer Straße 12-15, in the immediate vicinity of the Schöneberg S-Bahn station and in a central location between Berlin Schönefeld Airport and the government district.

“EUREF Campus 12–13” – *model new building:*

The building stands tall as the First ten-storey new building on the Campus with a two-level underground car park. Construction began in September 2011 and completed in late 2012. Built with state-of-the-art building technology, energy-saving insulation, triple-glazed windows, intelligent facades and an instabus system with energy management. Non-harmful, environmentally sustainable materials, which contributes to the achievement of LEED platinum certification.

[116]According to the official report prepared by Rem+ tec on the Haus 12-13 building, some relevant figures include:

The Gross floor area (GFA) = circa 19,900m² (BGF area DIN 277)

GFA above ground= circa 15250m²

GFA below ground = 4650m²

The total height from the ground level is 46.65m

The building consists of;

- A two-level underground garage with equipment surfaces
- A ground floor with separate input areas for parts of buildings on the left and right, and a key input for a Großrnieter whose land extend over the first three floors.
- Seven upper floors (typical) for office use, which can be divided into up to eight rental units. There are different types of offices such as cellular offices, combined offices and large offices to suit the needs of individual users.

The construction material for the walls, columns and floor slabs is reinforced concrete. the exterior wall system is insulated with authrazite and rockwool materials for thermal insulation in the buildings. The windows consist of curtain walls of triple glazed windows cut into sizes of 4.05m x 2.30m [117]

The roof is a well-insulated green roof of about 2140m² with down drain pipes for harvesting rain water. The 2009 EnEv regulations were met for thermal insulation. All exterior walls, floor slabs and ceilings are properly insulated.

[116] REM + tec Construction Management Description: EUREF Haus 12
[117] Revit architecture model

5.2. Software input and comparisons

CAD software like AutoCAD and ArchiCAD was used to generate the architectural drawings. Hence, enhancing interoperability between stakeholders by the file extension .DWG.

A regeneration of the Haus 12 three- dimensional model in Revit Architecture 2018 was done by the author. This was for the purpose of energy analysis simulation and supporting the sustainability certification process which is the aim of this research work. Hence, proper representation of building materials and detailing needed for effective energy simulation and other needs of building analysis. The model was assessed at the different level of development while designing the three-dimensional model. See the Appendix for more illustrations. Interoperability was more effective by using Revit because of the ease of exporting the finished file into IFC for IDA ICE energy simulation and model checking in SimpleBIM.

Other software used are Microsoft Excel for calculations of results from IDA ICE and Microsoft word for preparing this report.

5.2.1. Drawings and figures

The focus of this research is to discover how BIM tools can be used to assist the achievement of building sustainability certificates. The EUREF building in this context was modelled primarily with Revit architecture 2018 software as mentioned in 5.2 above and some of the highlights from the model as well as their relevance to this research are shown in this section.

5.3. Assessment of the building

The assessment of Haus 12-13 in comparison to the sustainable rating systems studied in this research is analysed. The aim is to compare the standards the building possesses with the other rating systems and consequently help in achieving their certifications

Since the reference model Haus 12-13 is already LEED certified building, in the BD+C i.e. Building Design and Construction category, the scheme New construction and its criteria sets will be examined in this section. Furthermore, the criteria set of BREEAM;

DGNB and HQE if applicable will also be analysed in comparison to the building attriubtes. Possibilities of BIM implementation according to the different criteria sets will be examined to get results which will be discussed in the course of this research.

Fig. 20: 3-dimensional model in Revit

Fig. 21: First floor plan iin Revit

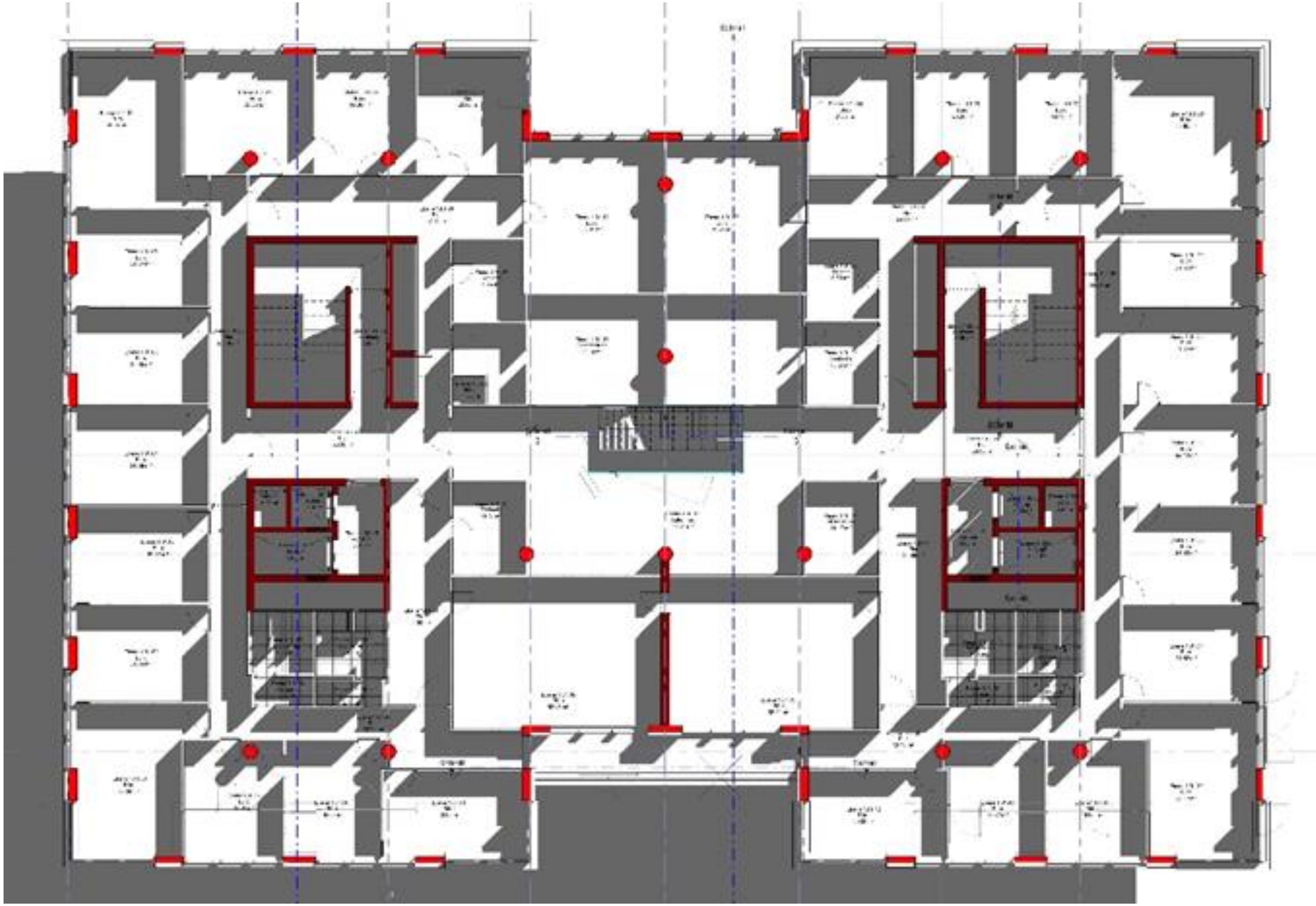

Table 14:LEED Pre-estimation of the EUREF Building

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name: EUREF HAUS 12-13
Date: 02:08:2018

Y	?	N				
	1		Credit	Integrative Process	1	

8	4	2		Location and Transportation	16	BIM TOOL
			Credit	LEED for Neighborhood Development Location	16	
	1		Credit	Sensitive Land Protection	1	
		2	Credit	High Priority Site	2	
	3		Credit	Surrounding Density and Diverse Uses	5	
5			Credit	Access to Quality Transit	5	
1			Credit	Bicycle Facilities	1	Revit
1			Credit	Reduced Parking Footprint	1	Revit
1			Credit	Green Vehicles	1	

8	2	0		Sustainable Sites	10	
Y			Prereq	Construction Activity Pollution Prevention	Required	
1			Credit	Site Assessment	1	Revit
	2		Credit	Site Development - Protect or Restore Habitat	2	Revit
1			Credit	Open Space	1	Revit
3			Credit	Rainwater Management	3	Revit
2			Credit	Heat Island Reduction	2	Revit
1			Credit	Light Pollution Reduction	1	GBS; ECOTECT

9	2	0		Water Efficiency	11	
Y			Prereq	Outdoor Water Use Reduction	Required	
Y			Prereq	Indoor Water Use Reduction	Required	
Y			Prereq	Building-Level Water Metering	Required	
2			Credit	Outdoor Water Use Reduction	2	
6			Credit	Indoor Water Use Reduction	6	
	2		Credit	Cooling Tower Water Use	2	
1			Credit	Water Metering	1	GBS

31	2	0		Energy and Atmosphere	33	
Y			Prereq	Fundamental Commissioning and Verification	Required	
Y			Prereq	Minimum Energy Performance	Required	
Y			Prereq	Building-Level Energy Metering	Required	
Y			Prereq	Fundamental Refrigerant Management	Required	
6			Credit	Enhanced Commissioning	6	IDA ICE
18			Credit	Optimize Energy Performance	18	IDA ICE
1			Credit	Advanced Energy Metering	1	IDA ICE
	2		Credit	Demand Response	2	
3			Credit	Renewable Energy Production	3	Revit
1			Credit	Enhanced Refrigerant Management	1	
2			Credit	Green Power and Carbon Offsets	2	Revit

9	4	0		Materials and Resources	13	BIM TOOL
Y			Prereq	Storage and Collection of Recyclables	Required	
Y			Prereq	Construction and Demolition Waste Management Planning	Required	
5			Credit	Building Life-Cycle Impact Reduction	5	Revit
	2		Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2	Revit
2			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	Vico; Revit
	2		Credit	Building Product Disclosure and Optimization - Material Ingredients	2	
2			Credit	Construction and Demolition Waste Management	2	Vico

13	2	0		Indoor Environmental Quality	16	
Y			Prereq	Minimum Indoor Air Quality Performance	Required	
Y			Prereq	Environmental Tobacco Smoke Control	Required	
2			Credit	Enhanced Indoor Air Quality Strategies	2	IDA ICE
3			Credit	Low-Emitting Materials	3	Revit
1			Credit	Construction Indoor Air Quality Management Plan	1	
	1		Credit	Indoor Air Quality Assessment	2	
1			Credit	Thermal Comfort	1	IDA ICE
2			Credit	Interior Lighting	2	GBS
3			Credit	Daylight	3	Revit
1			Credit	Quality Views	1	
	1		Credit	Acoustic Performance	1	

5	1	0		Innovation	6	
5			Credit	Innovation	5	
	1		Credit	LEED Accredited Professional	1	

0	4	0		Regional Priority	4	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	

83	22	2	TOTALS	Possible Points:	110

Certified: 40 to 49 points, Silver: 50 to 59 points, Gold: 60 to 79 points, Platinum: 80 to 110

Points related to BIM	75
Points achieved by BIM	60
Missing points that could be achieved by BIM	15

[118]LEED certification pre-estimation to check for the certification level of the EUREF building currently in v4 New construction BD+C category 2016. Source: Template from LEED/USGBC and the pre-estimate is by the author.

BREEAM-NOR 2016 New Construction Pre-Assessment Estimator: Building Performance

		Initial target setting	
Building name		Indicative BREEAM-NOR rating	Excellent*
EUREF HAUS 12-13		Indicative total score	85.9 %
Pre-Assessment Estimator Version: 1.06		Min. standards level achieved	Excellent

* = The rating has been limited to the min. standards level achieved

BREEAM-NOR 2016 Issue	Available credits	Credits	Contribution to score	Minimum standards level achieved	Respon-sible	Stat.
MANAGEMENT						
Man 01 Project brief and design	4	4	2.4 %	N/A		
Man 02 Life cycle cost and service life planning	4	3	1.8 %	N/A		
Man 03 Responsible construction practices	6	5	3.0 %	Outstanding		
Man 04 Commissioning and handover	3	3	1.8 %	Outstanding		
Man 05 Aftercare	3	2	1.2 %	Outstanding		
Total performance management	**20**		**10.2 %**	Credits achieved: 17		
HEALTH & WELLBEING						
Hea 01 Visual comfort	4	4	3.3 %	Outstanding		
Hea 01 Visual comfort - Criteria 1	Yes/No	Yes	-	Outstanding		
Hea 02 Indoor air quality	5	4	3.3 %	Outstanding		
Hea 03 Thermal comfort	2	1	0.8 %	N/A		
Hea 04 Microbial contamination	1	0	0.0 %	N/A		
Hea 05 Acoustic performance	2	1	0.8 %	N/A		
Hea 06 Safe access	0		0.0 %	N/A		
Hea 07 Natural Hazards	1	0	0.0 %	N/A		
Hea 08 Private space	0		0.0 %	N/A		
Hea 09 Moisture protection	3	2	1.7 %	Outstanding		
Total performance health & wellbeing	**18**		**10.0 %**	Credits achieved: 12		

Table 15: BREEAM Pre-estimation of the EUREF Building

BREEAM-NOR 2016 Issue	Available credits	Credits	Contribution to score	Minimum standards level achieved
ENERGY				
Ene 01 Energy efficiency	12	10	8.6 %	Outstanding
Ene 02 Energy monitoring	3	3	2.6 %	Outstanding
Ene 03 External lighting	1	1	0.9 %	N/A
Ene 04 Low and zero carbon technologies	2	2	1.7 %	Outstanding
Ene 05 Energy efficient cold storage	0		0.0 %	N/A
Ene 06 Energy efficient transportation systems	0		0.0 %	N/A
Ene 07 Energy Efficient Laboratory Systems	0		0.0 %	N/A
Ene 08 Energy efficient equipment	2	2	1.7 %	N/A
Ene 09 Drying space	0		0.0 %	N/A
Ene 23 Energy performance of building structure and installations	2	1	0.9 %	Excellent
Total performance energy	**22**		**16.4 %**	Credits achieved: 19

TRANSPORT				
Tra 01 Public transport accessibility	3	2	2.2 %	N/A
Tra 02 Proximity to amenities	1	0	0.0 %	N/A
Tra 03 Alternative modes of transport	2	2	2.2 %	N/A
Tra 04 Maximum car parking capacity	2	2	2.2 %	N/A
Tra 05 Travel plan	1	1	1.1 %	N/A
Tra 06 Home office	0		0.0 %	N/A
Total performance transport	**9**		**7.8 %**	Credits achieved: 7

WATER				
Wat 01 Water consumption	5	3	1.9 %	Outstanding
Wat 02 Water monitoring	1	1	0.6 %	N/A
Wat 03 Water leak detection and prevention	2	1	0.6 %	N/A
Wat 04 Water efficient equipment	0		0.0 %	N/A
Total performance water	**8**		**3.1 %**	Credits achieved: 5

BREEAM-NOR 2016 Issue	Available credits	Credits	Contribution to score	Minimum standards level achieved
MATERIALS				
Mat 01 Life cycle impacts	7	5	6.1 %	Outstanding
Mat 01 Life cycle impacts - Criteria 1	Yes/No	Yes	-	Outstanding
Mat 03 Responsible sourcing of materials	3	2	2.5 %	Outstanding
Mat 03 Responsible sourcing of mat. - Crit 1.	Yes/No	Yes	-	Outstanding
Mat 05 Designing for robustness	1	1	1.2 %	N/A
Total performance materials	**11**		**9.8 %**	Credits achieved: 8
WASTE				
Wst 01 Construction waste management	3	2	2.5 %	Outstanding
Wst 02 Recycled aggregates	1	1	1.3 %	N/A
Wst 03 Operational waste	1	1	1.3 %	Outstanding
Wst 04 Speculative floor and ceiling finishes	1	0	0.0 %	N/A
Total performance waste	**6**		**5.0 %**	Credits achieved: 4
LAND USE & ECOLOGY				
LE 01 Site selection	3	3	3.0 %	N/A
LE 02 Ecological value of site and protection of ecological features	2	2	2.0 %	N/A
LE 04 Enhancing site ecology	3	2	2.0 %	N/A
LE 05 Long term impact on biodiversity	2	1	1.0 %	N/A
LE 06 Building footprint	0		0.0 %	N/A
Total performance land use and ecology	**10**		**8.0 %**	Credits achieved: 8
POLLUTION				
POL 01 Impacts of refrigerants	3	1	0.6 %	N/A
POL 02 NOx emissions	3	2	1.2 %	N/A
POL 03 Surface water run-off	5	4	2.5 %	N/A
POL 04 Reduction of night time light pollution	1	1	0.6 %	N/A
POL 05 Noise attenuation	1	1	0.6 %	N/A
Total performance pollution	**13**		**5.5 %**	Credits achieved: 9

BREEAM-NOR 2016 Issue	Available credits	Credits	Contribution to score	Minimum standards level achieved
EXEMPLARY LEVEL AND INNOVATION (max 10 credits)				
Inn 01 - Man 05 Aftercare	1	1	1.0 %	N/A
Inn 02 - Hea 02 Indoor air quality	1	1	1.0 %	N/A
Inn 03 - Tra 03 Alternative modes of transport	1	1	1.0 %	N/A
Inn 04 - Wat 01 Water consumption	1	1	1.0 %	N/A
Inn 05 - Mat 01 Life cycle impacts	2	1	1.0 %	N/A
Inn 06 - Mat 03 Responsible sourcing of materials	1	1	1.0 %	N/A
Inn 07 - Wst 01 Construction site waste man.	1	1	1.0 %	N/A
Inn 08 - Wst 02 Recycled aggregates	1	0	0.0 %	N/A
Inn 09 - Approved innovation credits	10	5	5.0 %	N/A
Total indicative environmental section performance	**10**		**10.0 %**	Credits achieved: 10

Topic	Criteria group	Criteria no.	Criterion	Credit require	Credit Earned	Weight%
	DGNB OFFICES VERSION 2018					
Environmental quality (ENV)	Effects on the global and local environment (ENV 10)	ENV 1.1	Life cycle assessment	8	5	9.50%
		ENV 1.2	Local environmental impact	4	2.5	4.70%
		ENV 1.3	Responsible procurement	2	1	2.40%
	Resource consumption and waste generation (ENV20)	ENV 2.2	Drinking water demand and waste water volume	2	2	2.40%
		ENV 2.3	Land use	2	2	2.40%
		ENV2.4	Biodiversity at the site	1	0	1.20%
Economic quality (ECO)	Life Cycle cost (ECO10)	ECO1.1	Life Cycle cost	4	3	10.00%
	Economic development (ECO20)	ECO 2.1	Flexibility and adaptability	3	2	7.50%
		ECO 2.2	Commercial viability	2	2	5.00%
Sociocultural and functional quality (SOC)						
	Health, comfort and user satisfaction (SOC10)	SOC1.1	Thermal comfort	4	4	4.10%
		SOC1.2	Indoor air quality	5	4	5.10%
		SOC1.3	Acoustic comfort	2	2	2.00%
		SOC1.4	Visual comfort	3	3	3.10%
		SOC1.5	User control	2	2	2.00%
		SOC1.6	Quality of outdoor spaces	2	1	2.00%
		SOC1.7	Safety and security	1	1	1.00%
	Functionality (SOC20)	SOC 2.1	Design for all	3	3	3.10%
		SOC 2.2	Public access	2	2	1.70%
		SOC 2.3	Cyclist facilities	1	1	0.90%
	Design quality (SOC30)	SOC 3.1	Design and urban quality	3	3	2.60%
		SOC 3.2	Integrated public art	1	1	0.90%
		SOC 3.3	Layout quality	1	1	0.90%
				58	47.5	

Table 16: DGNB Pre-estimate of the EUREF Building

	DGNB OFFICES VERSION 2018					
Topic	Criteria group	Criteria no.	Criterion	Credit	Credit Earned	Weight%
Technical quality (TEC)	Technical quality (TEC10)	TEC1.2	Sound insulation	2	1	4.1
		TEC1.3	Building envelope quality	2	2	4.1
		TEC1.4	Use and integration of building technology	1	1	2
		TEC1.5	Ease of cleaning building components	2	1	4.1
		TEC1.6	Ease of recovery and recycling	2	2	4.1
		TEC1.7	Immisions control	0	0	0
		TEC 3.1	Mobility infrastructure	3	2	2.3
Process quality (PRO)	Planning quality (PRO10)	PRO1.1	Comprehensive project brief	3	2	1.4
		PRO1.4	Sustainability aspects in tender phase	2	2	1
		PRO1.5	Documentation for facility management	2	2	1
		PRO1.6	Procedure for Urban and design planning	3	2	1.6
		PRO2.1	Construction site/process	2	2	1
	Construction quality (PRO10)	PRO2.2	Construction quality assurance	3	2	1.4
		PRO2.3	Systematic commissioning	3	2	1.4
		PRO2.4	User communication	2	1	1.1
		PRO2.5	FM-Compliant planning	1	1	0.5
Site quality (SITE)	Site quality (SITE10)	SITE 1.1	Local Environment	2	2	1.1
		SITE 1.2	Influence on district	2	2	1.1
		SITE 1.3	Transport access	2	2	1.1
		SITE 1.4	Access to amenities	3	2	1.7
				42	33	
	Total credits available					80.5
Total credits required						100

5.4. Evaluation of the credits and standards with BIM input

The analysis of this research will not be complete without a direct comparison of the input of BIM into the pre-estimation of attaining a particular certification. This aims at comparing the influence of implementing BIM into these rating systems and the possibilities of achieving more points in other to be awarded a better rating. For instance, if the pre-estimate without BIM gives you a Silver rating, is it possible to improve to a Gold rating by certain considerations?

This section aims to find out if there's such possibility or not and what is the difference in doing this. The three certifications assessed previously in 5.3 will be adopted for this evaluation.

- LEED V4
- BREEAM
- DGNB

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name: EUREF HAUS 12-13
Date: 02:08:2018

Y	?	N			Points	BIM TOOL
	1		Credit	Integrative Process	1	
8	**4**	**2**		**Location and Transportation**	**16**	**BIM TOOL**
			Credit	LEED for Neighborhood Development Location	16	
	1		Credit	Sensitive Land Protection	1	
		2	Credit	High Priority Site	2	
	3		Credit	Surrounding Density and Diverse Uses	5	
5			Credit	Access to Quality Transit	5	
1			Credit	Bicycle Facilities	1	Revit
1			Credit	Reduced Parking Footprint	1	Revit
1			Credit	Green Vehicles	1	
8	**2**	**0**		**Sustainable Sites**	**10**	
Y			Prereq	Construction Activity Pollution Prevention	Required	
1			Credit	Site Assessment	1	Revit
	2		Credit	Site Development - Protect or Restore Habitat	2	Revit
1			Credit	Open Space	1	Revit
3			Credit	Rainwater Management	3	Revit
2			Credit	Heat Island Reduction	2	Revit
1			Credit	Light Pollution Reduction	1	GBS; ECOTECT
9	**2**	**0**		**Water Efficiency**	**11**	
Y			Prereq	Outdoor Water Use Reduction	Required	
Y			Prereq	Indoor Water Use Reduction	Required	
Y			Prereq	Building-Level Water Metering	Required	
2			Credit	Outdoor Water Use Reduction	2	
6			Credit	Indoor Water Use Reduction	6	
	2		Credit	Cooling Tower Water Use	2	
1			Credit	Water Metering	1	GBS
31	**2**	**0**		**Energy and Atmosphere**	**33**	
Y			Prereq	Fundamental Commissioning and Verification	Required	
Y			Prereq	Minimum Energy Performance	Required	
Y			Prereq	Building-Level Energy Metering	Required	
Y			Prereq	Fundamental Refrigerant Management	Required	
6			Credit	Enhanced Commissioning	6	IDA ICE
18			Credit	Optimize Energy Performance	18	IDA ICE
1			Credit	Advanced Energy Metering	1	IDA ICE
	2		Credit	Demand Response	2	
3			Credit	Renewable Energy Production	3	Revit
1			Credit	Enhanced Refrigerant Management	1	
2			Credit	Green Power and Carbon Offsets	2	Revit

Y	?	N			Points	BIM TOOL
9	**4**	**0**		**Materials and Resources**	**13**	**BIM TOOL**
Y			Prereq	Storage and Collection of Recyclables	Required	
Y			Prereq	Construction and Demolition Waste Management Planning	Required	
5			Credit	Building Life-Cycle Impact Reduction	5	Revit
	2		Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2	Revit
2			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	Vico; Revit
	2		Credit	Building Product Disclosure and Optimization - Material Ingredients	2	
2			Credit	Construction and Demolition Waste Management	2	Vico
13	**2**	**0**		**Indoor Environmental Quality**	**16**	
Y			Prereq	Minimum Indoor Air Quality Performance	Required	
Y			Prereq	Environmental Tobacco Smoke Control	Required	
2			Credit	Enhanced Indoor Air Quality Strategies	2	IDA ICE
3			Credit	Low-Emitting Materials	3	Revit
1			Credit	Construction Indoor Air Quality Management Plan	1	
	1		Credit	Indoor Air Quality Assessment	2	
1			Credit	Thermal Comfort	1	IDA ICE
2			Credit	Interior Lighting	2	GBS
3			Credit	Daylight	3	Revit
1			Credit	Quality Views	1	
	1		Credit	Acoustic Performance	1	
5	**1**	**0**		**Innovation**	**6**	
5			Credit	Innovation	5	
	1		Credit	LEED Accredited Professional	1	
0	**4**	**0**		**Regional Priority**	**4**	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	
	1		Credit	Regional Priority: Specific Credit	1	
83	**22**	**2**		**TOTALS** Possible Points:	**110**	

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Points related to BIM	75
Points achieved by BIM	60
Missing points that could be achieved by BIM	15

Table 17: LEED Pre-estimate with BIM input

Table 18: BREEAM Pre-estimate with BIM Input

CREDIT DESCRIPTION	CREDIT VALUE	BIM WITH CREDIT	BIM TOOL	EARNED POINTS
Management	**20**			**7**
Man 01: Project brief and design	4	Yes	Revit	2
Man 02: Life cycle cost and service life planning	4	Yes	Vico	2
Man 03: Responsible construction practices	6	No	N/A	0
Man 04: Commission and handover	3	No	N/A	0
Man 05: Aftercare	3	Yes	Revit	3
Health and well being	**18**			**9**
Hea 01: Visual comfort	4		Revit; GBS	2
Hea 02: Indoor air quality	5	Yes	GBS; Ecotect	3
Hea 03: Thermal comfort	2	Yes	IDA ICE	2
Hea 04: Microbial contamination	1	No	N/A	0
Hea 05: Acoustic performance	2	No	COM-SOL	0
Hea 06: Safe access	0	No	N/A	0
Hea 07: Natural Hazards	1			
Hea 08: Private space	0			
Hea 09: Moisture protection	3	Yes	Revit	2
Energy	**22**			**16**
Ene 01: Energy efficiency	12	Yes	IDA ICE	8
Ene 02: Energy monitoring	3	Yes	IDA ICE	3
Ene 03: External lighting	1	Yes	GBS	1
Ene 04: Low and zero carbon technologies	2	Yes	Revit	2
Ene 05: Energy efficient cold storage	0			
Ene 06: Energy efficient transportation systems	0			
Ene 07: Energy efficient laboratory systems	0			
Ene 08: Energy efficient equipment	2	No		
Ene 09: Drying space	0			
Ene 23: Energy performance of building structure and installations	2	Yes	IDA ICE	2
Transport	**9**			**4**
Tra 01: Public transport accessibility	3	Yes	Revit	
Tra 02: Proximity to amenities	1			

Tra 03: Alternative modes of transport	2	Yes	Revit	2
Tra 04: Maximum car parking capacity	2	Yes	Revit	2
Tra 05: Travel plan	1	No	N/A	
Tra 06: Home office	0			
Water	**8**			**6**
Wat 01: Water consumption	5		GBS	3
Wat 02: Water monitoring	1		GBS	1
Wat 03: Water leak detection and prevention	2		MagiCAD	2
Wat 04: Water efficient equipment	0			
Materials	**11**			**8**
Mat 01: Life cycle impacts	7		Revit	4
Mat 02: Responsible sourcing of materials	3		Vico	3
Mat 03: Designing for robustness	1		Revit	1
Waste	6			4
Wst 01: Construction waste management	3		vico	3
Wst 02: Recycled aggregates	1			
Wst 03: Operational waste	1			
Wst 04: Speculative floor and ceiling finishes	1		Revit	1

Land use & Ecology	**10**			**5**
LE 01: Site selection	3	No	N/A	0
LE 02: Ecological value of site and protection of ecological features	2	Yes	Ecotect	2
LE 04: Enhancing site ecology	3	yes	Ecotect	3
LE 05: Long term impact on biodiversity	2	No	N/A	0
LE 06. Building footprint	0			
Pollution	**11**			**5**
Pol 01: Impact of refrigerants	3			
Pol 02: No emissions	3			

Pol 03: Surface water run off	5		Ecotect	4
Pol 04: Reduction of night time light pollu-tion	1		GBS	1
Pol 05: Noise attenuation	1			
INNOVATION	**10**			**0**
Inno 01: Man 05 Aftercare	1	Yes		1
Inno 02: Hea 02 Indoor air quality	1	Yes		1
Inno 03: Tra 03 Alternative mode of transport	1	Yes		1
Inno 04: Wat 01 Water consumption	1			1
Inno 05: Mat 01 Life cycle Impacts	2			
Inno 06: Mat 03 Responsible sourcing of materials	1	Yes		1
Inno 07: Wst 01 Construction site waste man.	1	Yes		1
Inno 08: Wst 02 Recycled aggregate	1			
Inno 09: Approved innovation credits	10			
TOTAL POINTS WITH BIM				**64**

DGNB

	DGNB OFFICES VERSION 2018							
Topic	Criteria group	Criteria no.	Criterion	Credit	Weight%	WITH BIM	BIM TOOL	EARNED POINT
Environmental quality (ENV)	Effects on the global and local environment (ENV 10)	ENV 1.1	Life cycle assessment	8	9.50%	No		
		ENV 1.2	Local environmental impact	4	4.70%	No		
		ENV 1.3	Responsible procurement	2	2.40%	No		
	Resource consumption and waste generation (ENV20)	ENV 2.2	Drinking water demand and waste water volume	2	2.40%	Yes	Ecotect	2
		ENV 2.3	Land use	2	2.40%	Yes	Revit	2
		ENV2.4	Biodiversity at the site	1	1.20%	No		
Economic quality (ECO)	Life Cycle cost (ECO10)	ECO1.1	Life Cycle cost	4	10.00%	Yes	Vico	3
	Economic development (ECO20)	ECO 2.1	Flexibility and adaptability	3	7.50%	Yes	Revit	3
		ECO 2.2	Commercial viability	2	5.00%	No		
Sociocultural and functional quality (SOC)								
	Health, comfort and user satisfaction (SOC10)	SOC1.1	Thermal comfort	4	4.10%	Yes	GBS	4
		SOC1.2	Indoor air quality	5	5.10%	Yes	Ecotect	5
		SOC1.3	Acoustic comfort	2	2.00%	Yes	COMSOL	1
		SOC1.4	Visual comfort	3	3.10%	Yes	Revit	2
		SOC1.5	User control	2	2.00%	No		
		SOC1.6	Quality of outdoor spaces	2	2.00%	Yes	Revit	2
		SOC1.7	Safety and security	1	1.00%	Yes	Revit	1
	Functionality (SOC20)	SOC 2.1	Design for all	3	3.10%	Yes	Revit	2
		SOC 2.2	Public access	2	1.70%	Yes	Revit	1
		SOC 2.3	Cyclist facilities	1	0.90%	Yes	Revit	1
	Design quality (SOC30)	SOC 3.1	Design and urban quality	3	2.60%	Yes	Revit	2
		SOC 3.2	Integrated public art	1	0.90%	Yes	Revit	1
		SOC 3.3	Layout quality	1	0.90%	Yes	Revit	1
				58				33

		DGNB OFFICES VERSION 2018							
	Topic	Criteria group	Criteria no.	Criterion	Credit	Weight%	WITH BIM	BIM TOOL	EARNED POINT
	Technical quality (TEC)	Technical quality (TEC10)	TEC1.2	Sound insulation	2	4.1	Yes		2
			TEC1.3	Building envelope quality	2	4.1	Yes	GBS	2
			TEC1.4	Use and integration of building technology	1	2	Yes	Revit	1
			TEC1.5	Ease of cleaning building components	2	4.1	No		
			TEC1.6	Ease of recovery and recycling	2	4.1	No		
			TEC1.7	Immisions control	0	0			
			TEC 3.1	Mobility infrastructure	3	2.3			
	Process quality (PRO)	Planning quality (PRO10)	PRO1.1	Comprehensive project brief	3	1.4	Yes	Revit	3
			PRO1.4	Sustainability aspects in tender phase	2	1			
			PRO1.5	Documentation for facility management	2	1			
			PRO1.6	Procedure for Urban and design planning	3	1.6	Yes	Revit	3
			PRO2.1	Construction site/process	2	1			
		Construction quality (PRO10)	PRO2.2	Construction quality assurance	3	1.4			
			PRO2.3	Systematic commissioning	3	1.4			
			PRO2.4	User communication	2	1.1			
			PRO2.5	FM-Compliant planning	1	0.5			
	Site quality (SITE)	Site quality (SITE10)	SITE 1.1	Local Environment	2	1.1			
			SITE 1.2	Influence on district	2	1.1			
			SITE 1.3	Transport access	2	1.1	Yes	Revit	3
			SITE 1.4	Access to amenities	3	1.7	Yes	Revit	3
					42				17
				Total possible points earned by BIM				50	
				Total credits required				100	

Table 19: DGNB Pre-estimate with BIM Input

6.0. DISCUSSION

6.1. Collection of findings

The analysis of selected rating systems comparing their similarities, features, characteristics and prerequisites proves to be important in various ways. The rating systems analyzed in this research were carefully selected based on their popularity and use in the European continent.

A case study of an existing building which possess the highest level of LEED certification award (Platinum) was carried out, see *5.1* above; firstly, reviewing the features and attributes of the building and consequently a pre-estimation of the possible credits needed to attain this award was also done with the LEED New construction BD+C pre-estimation criteria set as shown in *Table 14* above. Furthermore, the pre-estimation was executed for BREEAM and DGNB certifications respectively. HQE criteria set was not found because the certification has no weighting system for its different criteria. The pre-estimations were done to directly compare the award systems and corresponding levels of LEED Platinum level to the other rating systems.

BIM was not left out at this point, as it is the focus of this research. Hence, after the pre-estimation without the input of BIM, another set of pre-estimations were done this time with BIM input, see 5.4 above; With the aim of checking the possible points that can be achieved by implementing BIM into the certifications. This has helped to view at a glance the importance of including BIM thereby enhancing the chances of attaining a higher rating in any of these certification systems.

All data used and well cited during this research leading to the achievement of the following results in 6.2 below was retrieved from Books, journals, reports, previous master and PhD thesis researches, relevant online information and Author’s findings from BIM software experience.

6.2. Results and Results analysis

After the assessment of the reference building was completed through pre-estimation of the selected rating systems, overall points were achieved which leads to the final certification level of the corresponding rating system illustrated below.

Table 20: Building assessment result

EUREF BUILINDG 12-13	CERTIFICATION	OVERALL CREDIT	RATING AWARDED
	LEED V4,	83	Platinum
	BREEAM 2016	85.9	Outstanding
	DGNB 2018[119]	80.5	Platinum

The current Criteria set of each certification was used and after the assessment, it was discovered that platinum rating in LEED maybe equal to the highest rating in the corresponding systems as shown in Table 20 above. Other observations include the fact that all these rating systems are channelled towards the same goal which is to achieve a sustainable environment. Therefore, some similarities in their criteria sets, descriptions, weights and even credits awarded. See corresponding tables in 4.3.2 and 5.3 above.

Furthermore, it was also observed that with the consideration and input of BIM, there is a high chance of achieving more than average score rating thereby improving the opportunities of getting a higher sustainable rating. From the assessments done in 5.4 above, the following were discovered.

LEED overall points required = 110

LEED points related to BIM input = 75

BREEAM overall points required = 109

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[119] (DGNB, 2018)

BREEAM points related to BIM input = 64 (with innovation)

DGNB overall points required = 100

DGNB points related to BIM input = 50

From the results above, it is safe to deduce the implementation of BIM in supporting Sustainable building certifications cannot be underestimated. Due to the fact that it plays a vital role in improving the quality of the required credits involved.

RESULT ANALYSIS

The assessment of the evaluation of selected sustainability certifications described in 5.4 above shows that there are some similarities in the provided criteria sets cutting across these certifications. Since the focus of these certifications is to achieve a sustainable building and environment, the general similarities are shown in the comparison table of Table 12. However, from the implementation of BIM in achieving these rating systems, it was discovered that some criteria sets are required by all the certification systems. They include:

Visual comfort, Indoor air quality, Thermal comfort, Acoustic performance, Access to quality transport, Bicycle facilities (alternative transport), water metering, Building life cycle impacts, Life cycle costs. The successful application of these criteria sets, proves to achieve the corresponding credits as highlighted in the table below in addition to other criteria which require BIM or not within the certification systems.

CRITERIA	DESCRIPTION[120]	BREEAM	LEED	DGNB
Visual comfort	Provision of sufficient, uninterrupted supply of daylight and artificial light in all interior areas in constant use.	4	4	3
Indoor air quality	Sufficient provision of quality indoor air for well-being of users.	5	2	3

[120] (DGNB, 2018)

Thermal comfort	Balanced temperature in all interior spaces throughout the year.	2	1	4
Acoustic performance	Provision of acceptable room acoustic conditions.	2	1	1
Access to quality transit/ transport	Proper design of road networks, walkways and access routes through and from the building.	3	5	3
Bicycle facilities	Provision of bicycle facilities according to the certification requirements.	2	1	1
Water metering	Use of water measuring meters for effective water consumption management.	1	1	
Building life cycle impact	The monitoring of the impact of the building to its environment throughout its lifecycle.	7	5	7
Life cycle cost	sensible and conscious use of economic resources throughout the entire life cycle of a building.	4	-	4

Table 21: Common criteria for BIM input

6.3. Answers to the research questions

The success of any research is the ability to solve and answer the research questions with results and proofs to back it up. This section aims at answering all the research questions set at the beginning of this research based on the results provided and discussed during the process

1. *What are the different attributes that must be present in a building to attain a green certification?*

Each certification is unique in terms of the criteria (attributes) required to attain certification. This can be seen in the Table 7 and 8 shown above. However, there are some that are common to all the rating systems such as Indoor environmental quality which involves the consideration of thermal comfort, visual comfort, indoor air quality etc, Energy use and management, Innovation and many others. a comprehensive list can be found in Table 10 above.

2. *How can the standards be applied universally into the BIM system?*

A decision to implement BIM into the design early from the planning stage is one way to do this. If BIM is used with a projection of the desired certification and level to be attained, then the criteria set, and available credits will be easily worked out by putting a little more effort and use of efficient BIM software. A good example of this is the reference building used in this research. According to the construction documentation provided, the award of LEED Gold rating was initially aimed at from the beginning of the planning. Furthermore, creation of templates, work sets, components and other things into the BIM software relating to these required criteria will also facilitate the universal application of these standards into BIM system. The templates can be saved in a universally used extension such as .ifc or .dwg to encourage interoperability among users and stakeholders alike.

3. *How can these attributes be incorporated into the planning process to make it faster?*

An in-depth knowledge of the required criteria description and their mode of application is needed. If all these are well known by the designer, it will be easy to customize the BIM software to suit these criteria earlier on so as to avoid repetition and unnecessary mistakes during the planning process which tend to make it slow. Some BIM software are flexible; therefore, the customization may include creation of pre-sets, templates, work set, property sets materials, components and commands that the software will recognise and possibly the particular rating system to be achieved.

4. *Will a comparative analysis of the different sustainability building rating systems make building evaluation more efficient?*

Different studies have been carried out on the various rating systems that exist all around the world. It is generally believed that the reason of these comparisons previously carried out is to find the ‘best’ or most suitable. While these can be true, the issue of efficiency of the building evaluation cannot be left out. It is important to have a comparative analysis not only to find the most suitable but to discover other requirements similar or different from the selected rating systems that would enhance the efficiency of your building towards a greener environment. The chapter 4.1 above shows different comparisons done for the selected rating systems to enhance efficiency.Research methodology

6.4. Efficiency of BIM in supporting the certifications

The results derived in this research has helped to consolidate the efficiency of BIM implementation in supporting sustainable certifications. As extensively discussed in previous chapters 2.3 and 3.0 above, BIM is no longer an ideology but a necessary part of our construction industry today which has come to stay. Some of the ways which BIM supports sustainable certifications include;

Architectural planning and design phase: the most obvious use of BIM in building engineering and design modelling. Revit, ArchiCAD and a host of other design BIM softwares already exist for this purpose.

Energy analysis: for energy analysis simulation.

Also useful for cost estimation, quantity take off, HVAC design, renewable energy Carbon emission analysis and many other methods of application.

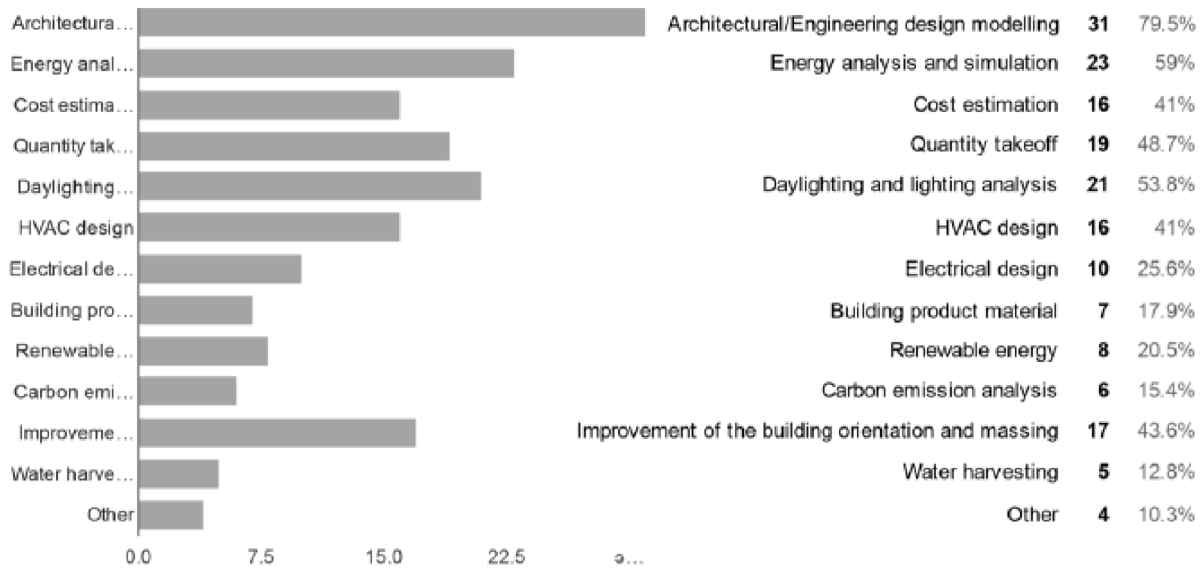


Fig. 23: BIM to support Sustainable rating systems

BIM is efficient because it helps to avoid or minimise errors, overlaps and gaps in the project design process, as well as saving time and money.

More sustainable buildings can be designed and built by using BIM sustainability tools. This allows for a more accurate analysis, flexibility and innovation. It also helps the evaluation and the improvement of sustainability, in relation to the buildings impact on the environment and also on its final cost. Many BIM platforms, like Revit or ArchiCAD, have included analysis and simulations tools. By creating multiple layers of information in parametric objects, material contents, work sets, pre-sets and templates, additional sustainable rating specified information can be directly included into the BIM models.

The major challenge with using BIM could be insufficient experience or familiarity with the software. Other challenges are highlighted in 3.1.2 above.

6.4.1. Recommendations for BIM and Sustainable certifications

Since it is already an established fact that BIM has come to stay, the need to improve on the challenges and disadvantages in order to ensure more efficiency in sustainability certifications is crucial. Some projections for this include;

- Improvement on interoperability possibilities between BIM and other analysis or simulation tools. Such as; file extensions, collaborations and universal use of files in other simulation or analysis software.

- BIM tools or software should be programmed to calculate sustainability credit points needed and achieved by the building per design phase until the design is complete.
- Inclusion of schedules, quick calculations, and credit requirements for rating systems should be considered. BIM already has the ability to calculate and prepare schedules, therefore, the sustainability rating factor should be integrated into the software so that it has a list of different certifications and their requirements and it can support the certification by certain programming of the design model to suit these in-built certifications.

7.0. CONCLUSION

Sustainability and BIM have gradually become an essential aspect of our environment with direct impact on the building's entire life cycle. Since they are both interconnected and continuously influencing each other, the AEC industry as a whole has the continuous task of accommodating this new trend and constantly adjusting to the changes that come with it. The more sustainable designs are implemented, the greater the demand for BIM software practices and experts. On the other hand, building sustainability practices become more popular and widely accepted because of the support and improvements made by BIM input in the design process.

Among the many benefits of sustainable buildings is the significant reduction of running costs and the negative impacts to the environment. Therefore, the inclusion of the three aspects (Environment, Economic and Social) of sustainability into the design process and certificate awarding process is very important. Since the concept of sustainable design is to consider the environment, people and costs, holistically, the need to consider more methods of including these aspects into the rating system is very important. Most rating systems mainly focus on sustainable design and leave the remaining aspects.

The focus of this research was to examine the different rating systems and how they can be supported by BIM. It is therefore recommended that BIM software be customized to fit these rating system requirements. If BIM is involved very early in the planning and design stage, a lot of costs and errors will be greatly reduced or totally avoided. BIM offers different tools to create more sustainable projects, by improving the performance of the buildings and allowing an integrative design process. Its tools help in determining building orientation and massing, daylighting, water harvesting, energy modelling, renewable energies and sustainable materials.

The popularity of BIM implementation is steadily increasing as well as the number of users. Therefore, the BIM software should be upgraded to improve the performance of the buildings and allow an integrative design process. This can be done by determining building orientation and massing, daylighting, water harvesting, energy modelling, renewable energies and sustainable materials.

Sustainability rating systems are open to all types of buildings in their entire life cycle phases and certifications are available for them. Therefore, BIM software can be adjusted to fit the sustainable requirements in various ways; such as, the development of additional tools to calculate and track the sustainable credits requirements; the improvement of the interoperability between BIM and other analysis and simulation tools; tools that check and prepare the necessary data from within a BIM solution to make the model more compatible with other analysis and simulation software solutions; inclusion of additional datasets in BIM technologies that allow more detailed energy analysis; integration of schedules of quick calculations especially developed for rating systems into the BIM software itself; and integration of additional material properties into BIM solutions.

Recently, improvements have been made in the newer versions of BIM software relating to the issue of interoperability, file extensions and compatibilities, quality of designs, planning processes, design components and software. However, more efforts need to be exerted to seamlessly eliminate this issue.

The study of BIM and sustainability certifications is not a new concept as various researches have been carried out previously to improve the issues posed in this matter. Solutions, suggestions and results have been deduced from the past researches according to the time frame which these researches were done. A lot of the issues raised previously has been solved today and more issues are now been raised.

In conclusion, additional recommendations for the future of BIM and sustainability certificate apart from the ones already mentioned in 6.4.1 above, include the creation of mobile applications or software that can open any BIM software generated file in order to enhance the communication among the professionals involved in a project. Instant messaging, corrections, adjustments, meeting schedules and other important information about the project can be easily communicated on the go thereby enhancing interoperability among the professionals.

DECLARATION OF AUTHORSHIP

I hereby declare that the attached master’s thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Date

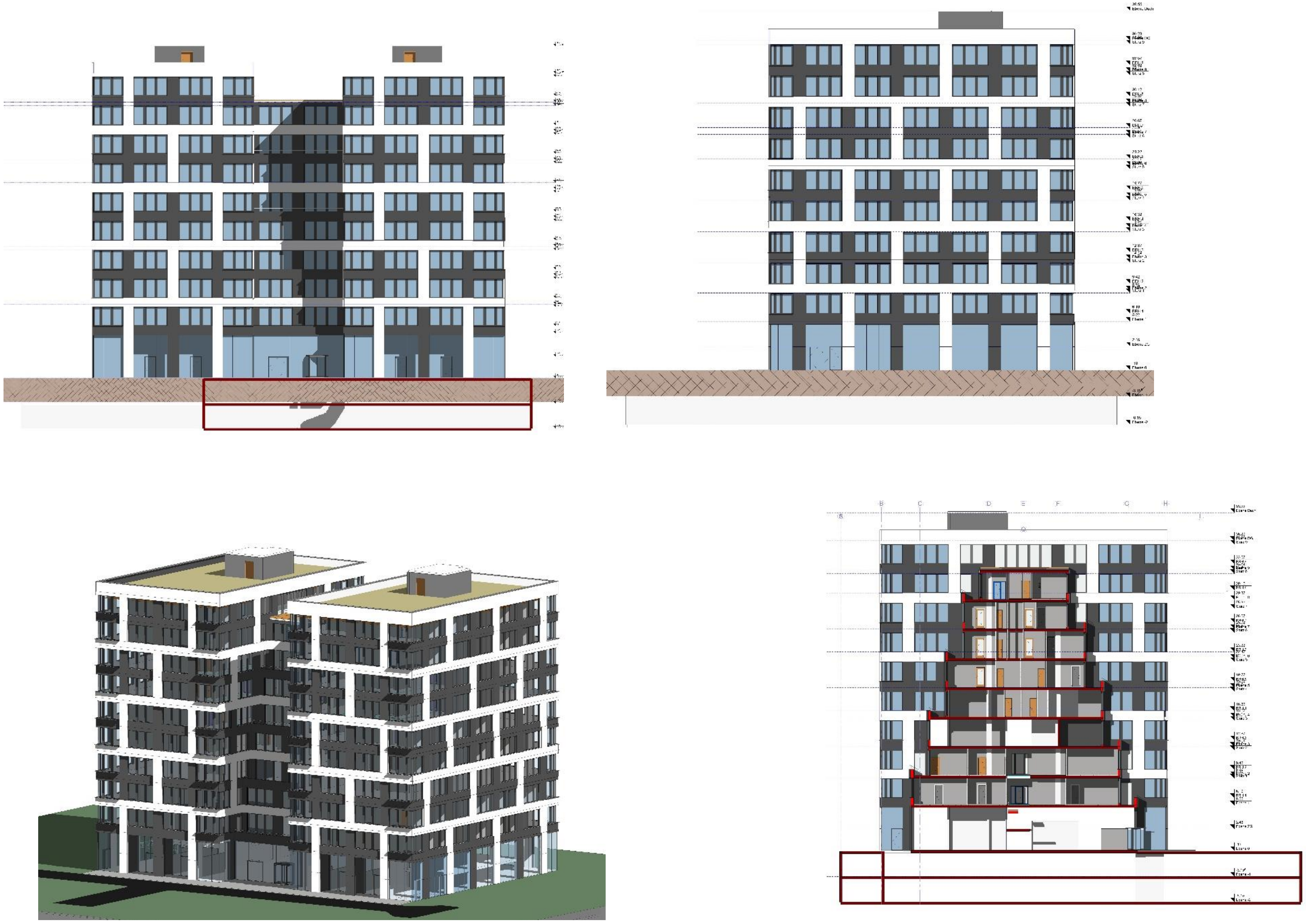
Signature of the student

APPENDIX 1

Fig. 25: First floor plan of EUREF Building 12-13 in Revit

Fig. 24: Eight floor plan in Revit

Fig. 26: Different views of the EUREF Building in Revit



BREEAM-NOR 2016 New Construction Pre-Assessment Estimator: Summary of Building Performance

NGBC

Overall Building Performance

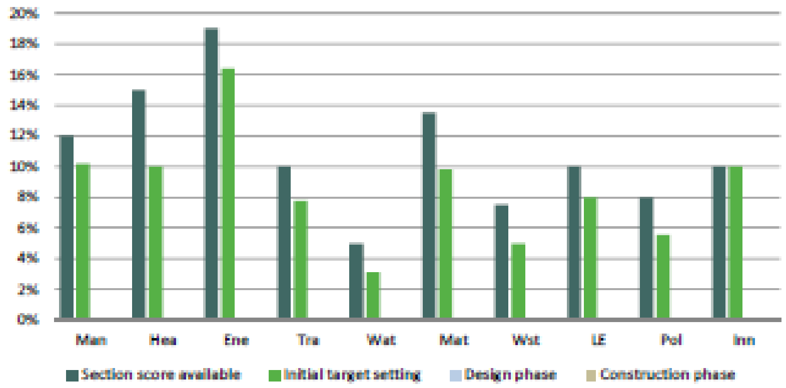
Building name	EUREF HAUS 12-13

Pre-Assessment Estimator Version: 1.06. Date: 1/25/2018

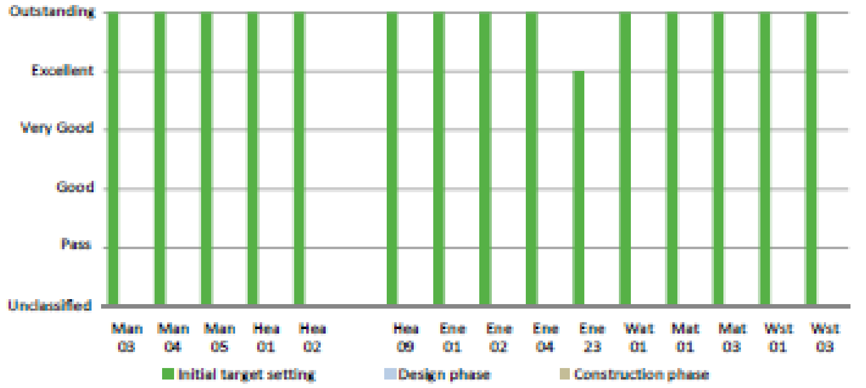
	Initial target setting	Design phase	Construction phase
Show results	Yes	No	No
Indicative BREEAM-NOR rating	Excellent*		
Indicative total score	85.9 %		
Min. standards level achieved	Excellent		

* = The rating has been limited to the min. standards level achieved

Building Performance by Environment Section



Min. standards level achieved



Environmental Section	No. credits available	Initial target setting Credits Achieved	Initial target setting % credits achieved					Weighting	Score Initial target setting		
Management	20	17	85%					12%	10%		
Health & Wellbeing	18	12	67%					15%	10%		
Energy	22	19	86%					19%	16%		
Transport	9	7	78%					10%	8%		
Water	8	5	63%					5%	3%		
Materials	11	8	73%					13.5 %	10%		
Waste	6	4	67%					7.5 %	5%		
Land Use & Ecology	10	8	80%					10%	8%		
Pollution	13	9	69%					8%	6%		
Innovation	10	10	100%					10%	10%		
Sum	127	99							85.9 %		
Indicative BREEAM-NOR rating									Excellent*		
Min. standards level achieved									Excellent		

* = The rating has been limited to the min. standards level achieved

Fig. 27: Results of BREEAM Pre-estimation

TOPIC	CRITERIA GROUP	CRITERION	OFFICE	EDUCATION	RESIDENTIAL	HOTEL	CONSUMER MARKET	SHOPPING CENTRE	COMMERCIAL BUILDING	LOGISTICS	PRODUCTION
ENVIRONMENTAL QUALITY (ENV)	EFFECTS ON THE GLOBAL AND LOCAL ENVIRONMENT (ENV1)	**ENV1.1**	8 9.5%	8 9.5%	8 9.5%	8 9.5%	8 9.5%	8 9.0%	8 9.5%	8 9.5%	8 9.5%
		ENV1.2	4 4.7%	4 4.7%	4 4.7%	4 4.7%	4 4.7%	4 4.5%	4 4.7%	4 4.7%	4 4.7%
		ENV1.3	2 2.4%	2 2.4%	2 2.4%	2 2.4%	2 2.4%	2 2.3%	2 2.4%	2 2.4%	2 2.4%
	RESOURCE CONSUMPTION AND WASTE GENERATION (ENV2)	**ENV2.2**	2 2.4%	2 2.4%	2 2.4%	2 2.4%	2 2.4%	2 2.3%	2 2.4%	2 2.4%	2 2.4%
		ENV2.3	2 2.4%	2 2.4%	2 2.4%	2 2.4%	2 2.4%	3 3.4%	2 2.4%	2 2.4%	2 2.4%
		ENV2.4	1 1.2%	1 1.2%	1 1.2%	1 1.2%	1 1.2%	1 1.1%	1 1.2%	1 1.2%	1 1.2%
ECONOMIC QUALITY (ECO)	LIFE CYCLE COST (ECO1)	**ECO1.1**	4 10.0%	4 10.0%	4 10.0%	4 10.0%	4 10.0%	4 10.0%	4 10.0%	4 10.0%	4 12.9%
	ECONOMIC DEVELOPMENT (ECO2)	**ECO2.1**	3 7.5%	3 7.5%	3 7.5%	3 7.5%	3 7.5%	3 7.5%	3 7.5%	3 7.5%	3 9.6%
		ECO2.2	2 5.0%	2 5.0%	2 5.0%	2 5.0%	2 5.0%	2 5.0%	2 5.0%	2 5.0%	0 0%
SOCIOCULTURAL AND FUNCTIONAL QUALITY (SOC)	HEALTH, COMFORT AND USER SATIS-FACTION (SOC1)	**SOC1.1**	4 4.1%	4 3.6%	4 4.3%	4 3.9%	4 4.5%	4 4.5%	4 4.5%	4 4.3%	4 4.3%
		SOC1.2	5 5.1%	5 4.5%	5 5.4%	5 4.9%	4 4.5%	4 4.5%	4 4.5%	5 5.4%	5 5.4%
		SOC1.3	2 2.0%	3 2.7%	0 0%	3 2.9%	0 0%	0 0%	0 0%	0 0%	0 0%
		SOC1.4	3 3.1%	3 2.7%	3 3.2%	2 2.0%	3 3.4%	3 3.4%	3 3.4%	3 3.2%	3 3.2%
		SOC1.5	2 2.0%	2 1.8%	2 2.1%	2 2.0%	2 2.3%	2 2.3%	2 2.3%	0 0%	0 0%
		SOC1.6	2 2.0%	2 1.8%	2 2.1%	2 2.0%	2 2.3%	2 2.3%	2 2.3%	5 5.4%	5 5.4%
		SOC1.7	1 1.0%	2 1.8%	1 1.1%	2 2.0%	1 1.1%	1 1.1%	1 1.1%	4 4.3%	4 4.3%
	FUNCTIONA-LITY (SOC2)	**SOC2.1**	3 3.1%	4 3.6%	4 4.3%	3 2.9%	4 4.5%	4 4.5%	4 4.5%	0 0%	0 0%

Fig. 28: Weighting of DGNB 2018 criteria (DGNB, 2018)[121]

[121] (DGNB, 2018)

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