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Assessing Residential Buildings Compliance with Sustainability Rating Systems through a BIM-Based Approach †

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Abstract: Using the semantic information available in building information models (BIM) during the whole project lifecycle enables faster, safer, and efficient construction, cost-effective operation and maintenance, and cost-effective eventual decommissioning. This paper aims to provide a systematic review of how sustainability rating systems can exploit the BIM approach for an easy collection of data and information and assessment of indicators to reach building certification. This paper is a part of the BIM4REN project, which is dedicated to developing an open-access platform of tools for the digitalization of the building renovation process specifically tailored for SMEs (Small and medium-sized enterprises).

Keywords: sustainability; BIM; rating systems; LEED; BREEAM

1. Introduction

1.1. Need to Make the Construction Industry More Efficient

"Sustainability" of the built environment first means saving energy by becoming more efficient. If we compare the productivity trend of the construction industry with the manufacturing one, as in **Error! Reference source not found.**Figure 1, it is clear that it is possible to improve significantly.

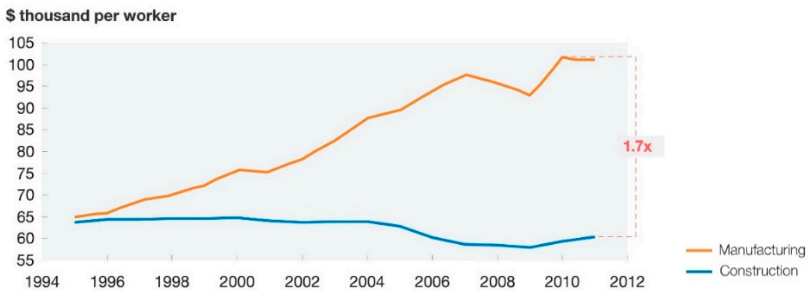

Figure 1. Construction productivity has been flat for decades, according to McKinsey research. In manufacturing, by contrast, productivity has nearly doubled over the same period, and continuous improvement has been the norm.

The increase in productivity of the manufacturing industry has been constant thanks to the introduction of new digital technologies, while that of construction has not managed to evolve. The introduction of the building information models (BIM) method makes it possible to achieve greater productivity by standardizing processes, making the construction industry processes more like the ones used by the manufacturing industry. There will always remain a certain gap between the two because in the design of the product, the design of a prototype can be optimized and then mass-produced, while in the architecture design elements, each building is a prototype.

1.2. To Have Smart Cities You Need to Have Smart Buildings

The search for sustainability has led to the concept of Smart City, an innovative idea of a city that relates the built environment of cities with the human, intellectual, and social capital of those who live there thanks to the widespread use of new technologies.

A full Smart City can only be obtained when every single building, whether pre-existing or newly built, is virtualized and transformed into a Smart Building: a set of data that can inform the administration for the management and development of the urban environment. BIM is the only way to move to digital design and management, producing Smart Buildings that will populate the Smart Cities of the future [1].

2. Sustainability Credits Requirements, What Can BIM Provide

2.1. Measuring Sustainability

For the word "sustainability" not to be reduced to a simple buzzword without content, it is necessary to be able to measure it. In this context, sustainability protocols such as LEED (Leadership in Energy and Environmental Design) (1992), BREEAM (Building Research Establishment Environmental Assessment Method) (1990), ESTIDAMA Pearl Rating System (2010), Envision Rating System for Infrastructure (2011), WELL (2014) were created. These evaluation systems certify a building at a certain level of sustainability: to reach the highest levels, it is necessary to set up an integrated design from the earliest stages and verify that the initial strategic choices are maintained until the construction of the work, inserting the control of third parties.

2.2. How BIM Can Support Sustainability Protocols

BIM and sustainability protocols share the same objectives: efficiency, quality and, therefore, sustainability. The BIM process facilitates collaboration between all disciplines, allowing an integrated design that would otherwise be difficult to achieve. It produced a virtual building which is essentially a searchable database already containing everything needed to assess the sustainability level of a building. The United Kingdom invested in this idea. Innovate UK in 2013 funded the research project "RegBIM Project" [2], which aims to create a tool for the automatic calculation of the sustainability assessment according to the BREEAM protocol starting from a BIM model in the Industry Foundation Class (IFC) format.

BIM, therefore, can have different definitions based on the point of view from which you look at it, but its main characteristics make it particularly suitable for supporting a sustainable design which involves a collaboration and a holistic approach.

2.3. BIM Is a Collaboration

One of the main objectives of BIM is to increase the collaboration between the different stakeholders. With the increasing complexity to be faced in the design of a building, one can no longer think of tackling this undertaking alone; instead, several specialists must coordinate to get the best result.

Thanks to BIM, it is possible to exchange information with energy analysis specialists, which is done through internationally standardized open exchange formats: IFC and gbXML [3].

Interoperability between different software is therefore essential to be able to carry out energy analysis from the outset and evaluate the most sustainable configurations right in the phase in which you still can modify the project.

2.4. BIM Is from the Concept of Demolition

The holistic approach of BIM is a real revolution in the world of construction: we no longer look at the building broken into its phases, but instead take the entire life cycle of the building into consideration. With BIM, you cannot just deal with design or construction or management without worrying about what comes first and what will happen next. The BIM Execution Plan is the document that must accompany all BIM projects which specifies how the information within the digital model must be structured so that it can be used in the subsequent phases of the building's life cycle.

The sustainability of a work can only be achieved by analyzing the building as a whole: it is no longer sufficient to integrate the various specialist disciplines or pay attention to design and construction alone, but it is necessary to always have an eye towards a broader horizon, that is, it is necessary to make the management and maintenance of the work sustainable.

A good example of this is being able to do the Life Cycle Assessment (LCA) using BIM Authoring Tools or through a quantity take-off from a BIM model [4].

2.5. Comparing Estidama's Pearls Rating System to LEED and BREEAM

International sustainability protocols have some differences, but common categories can be identified. Figure 2 [4] identifies the incidence of credits of different categories in three different sustainability protocols.

PEARLS		BREEAM		LEED	
Site selection and Natural systems	16%	Site Selection and ecology	20.5%	Site Selection	24.5%
Water	25%	Water	2.5%	Water	5.5%
Energy	25%	Energy	33%	Energy	33%
Materials	16%	Materials	13.5%	Materials	13.5%
Indoor Environmental Quality	20%	Indoor Environmental Quality	13%	Indoor Environmental Quality	14%
Innovation	2%	Innovation	6.5%	Innovation	6.5%
Integrated Design Process	7%	Facility management	12%	Regional Priority	4%

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Figure 2. Rating systems comparison table. The table is for general comparison purposes only, as it does not take point-less prerequisites into account. The names of some categories have been adjusted and some credits have been moved across categories to simplify the comparison.

In this study, we deepen the analysis of how BIM can support LEED certification, where the majority of scientific papers have been written [5,6], but show that the same concepts and processes can also be extended to other sustainability protocols after making the appropriate changes to the methods for calculating credits.

3. BIM and Sustainability Certification Integration

To describe the state of the art of using BIM methodology to support Green Building Certification, a selection of review papers is reported. The first paper analyzes all the issues related to digitalization of the green building assessment process, as calculation requirements, data needed and exchange of information between tools. The second and third papers specifically analyze the automation of the assessment procedure to allow replicability and interoperability of tools. The studies propose two different approaches: a rule-based method and a cloud computing method.

3.1. BIM Applications for Green Buildings

Ref. [7] provided a comprehensive analysis of BIM applications for green building assessment. They classified the different tools into the following groups: software tools, database infrastructures, data exchange modules, and plug-ins for specific criteria assessment. A summary of the analysis is reported below.

3.1.1. Application of Software Tools in Evaluating Assessment Criteria

Software tools to support Green Building Assessment (GBAS) criteria evaluation are categorized as BIM modeling tools, BIM-based performance assessment tools, and auxiliary tools. The first category includes software like Autodesk Revit Architecture and ArchiCAD, that are built on a parametric modeling technology which allows users to create designs from a combination of graphical and non-graphical data [8].

The second group of software (BIM-based performance tools) includes IES-VE, Safaira, Ecotect analysis, and Project Vasari. These tools have been associated with simulation-based quantitative criteria such as building energy use, water use, or indoor environment quality [9–11]. To evaluate these criteria, the BIM model must be imported into these software tools either manually or through automated queries. An appropriate data exchange platform is therefore required to reduce data losses.

Auxiliary tools such as Microsoft Excel and Access were also identified for data manipulation, storage and presentation of assessment results. IES, One Click LCA, and Autodesk had developed tools for evaluating and generating submittals for some LEED and BREEAM criteria.

3.1.2. Database Infrastructure

Databases can be classified as augmented, external, and functional databases. The first is the embedded library of building elements into BIM software such as Autodesk Revit, ArchiCAD, and IES-VE [12] from which users can construct a building envelope. The second is extrinsic to the BIM application. External databases range across online platforms to study-specifically designed platforms. In functional databases, the desired functionality significantly influences the tool that is used.

3.1.3. Data Exchange Modules

Manipulation of data between the BIM-related software involves interoperability issues, which may result in substantial data loss. Also, the ability to transfer assessment to populate GBAS templates represents an issue.

Exchange protocols identified from BIM/GBAS literature include gbXML schema, Industry Foundation Class (IFC), Open Database Connectivity (ODBC), and Construction Operations Building Information Exchange (COBie) [13].

gbXML schema facilitates the transfer of data between a database, BIM authoring, and simulation tools. This protocol defines information in BIM models by linking building geometries with descriptive data [14].

Industry foundation classes (IFC) supports information storage and enhanced interoperability among a broader range of software [15]. In exchanging data between software, IFC protocols provide and interpret relational and organizational data in the form of geometry and topology [16]. Unlike gbXML which allows representing only rectangular geometry, IFC can represent multiple geometrical shapes. Its placement function locates an object within a coordinate system by using two attributes: location and dim. Location is the geometric position of an item with regards to a reference point, and dim is the space dimension of the object [16].

COBie and ODBC allow overcoming issues connected with data loss during model transfer. In [13], COBie was also proposed as a protocol to incorporate unique data such as commissioning data. With the spreadsheet implementation of COBie, cumulative data structure facilitates data collection through the design, construction, commissioning, and handing-over stages of projects. Primarily, ODBC could be used to augment BIM models by integrating information that cannot be done with conventional methods. However, ODBC users can also extract building information in tabular forms accessible through database management software such as Microsoft Excel or Access [12]. These protocols are recommended for the final stage of BIM/GBAS automation to aggregate, evaluate, and propagate information into LEED templates.

3.1.4. Credit Assessment

Generally, credit assessments have required the extension of BIM software in the form of plugins or integration with some other tool functions [12]. They included an API, Microsoft Excel Macros, and Inbuilt extensions such as the Revit's Dynamo Visual Scripting, COBie, and a Cloud-Based Approach.

In the most basic form of assessment, users tag materials with desired properties, extract a material take-off, and evaluate the credits attained. There are some limitations such as extracting irrelevant information, double counting, or ignoring differences such as floor levels or schedules [17,18].

3.2. Rule-Based LEED Evaluation Method

Ref. [19] proposed the RLEM-BIM (rule-based LEED [Leadership in Energy & Environmental Design] evaluation method with BIM) approach, a method of defining and automating evaluation rules that can support the variability of LEED projects.

This variability is identified by the building type subject to evaluation, the items chosen for the sustainability assessment (e.g., Sustainable sites, Energy and Atmosphere), and the referred hierarchical requirements, from mandatory pre-requisites to selected credits. For LEED building performance evaluation, the necessary BIM data sources and evaluation procedures, therefore, vary according to the use case.

R-LEM focuses on supporting customization related to LEED evaluation like customizing the LEED assessment structure, customizing data items for LEED credit calculation, evaluation model calculation methods, and algorithm customization. Also, the hard-coding term is used to make a distinction from the commercial system where the user cannot customize the evaluation rule.

BIM data sources or evaluation procedures are defined in terms of a generalized operator so that the evaluation procedures will be defined based on rules. In this way, the procedure will not depend on solutions but instead can automate BIM-linked building performance evaluation.

Regarding the results of the analysis of the effects, experts reported that RLEM-BIM improved in terms of its variability and reusability, and it helped decrease errors and the rework rate due to manual work. Besides, if LEED evaluation is conducted based on RLEM-BIM, then the items can be immediately analyzed, thereby reducing the time spent on item analysis.

3.3. Cloud BIM for LEED Automation

The diversity of software applications and the variety of domain information needed for discipline-specific building simulations and analyses represent the major difficulty in using BIM methodology to support LEED rating system application. Although interoperability of software and plug-ins and use of proprietary file formats facilitate the digital flow of data and information, the complexity of LEED projects and the number of actors involved increasing the difficulty of collaborating on a same digital model.

A suggestion on creating an interoperable software environment based on open standards such as IFC to facilitate seamless and bidirectional information flow between individual project members, meeting individual model information needs in real-time without compromising the overall design process, the model integrity, or the anticipated building performance as prescribed in the LEED rating system [20]. It is quite apparent that this process cannot rely on traditional desktop applications. Cloud Computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [21].

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