Project Sustainability: criteria to be introduced in BIM

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Abstract

Quality in architecture has become a topic of strategic importance in the construction sector and it holds an increasingly important place in regulations adopted by European countries. To meet the parameters set for architectural quality, sustainability and green buildings assessment tools are crucial, whether the project concerns the narrowest scale of a building or the largest scale of a city. Related to that, a large number of countries has issued energy certification procedures that rate the energy performance of buildings.

The phase of conceptual design of a building is the most appropriate to integrate strategies meant to enhance sustainability. Implementing those strategies at the very beginning of the construction process, brings to cost reduction compared to doing so at a later stage.

A wide range of green building assessment tools and protocols has been developed to improve the quality of the design process; their goal is to cut energy consumption and environmental impacts in both the construction and the management phases and thus abiding also to regulations. A large number of studies has been published regarding those assessment tools; they are usually divided into 2 main groups:

a) based on a multi-criteria analysis, such as BREEAM, LEED, CASBEE

b) based on the Life Cycle Assessment (LCA) approach, such as BEES, BEAT, EcoQuantum.

The growing use of Building Information Modeling (BIM) plays a key role in this realm. It allows the evaluation of multiple design scenarios at the same time from an environmental and financial points of view. This paper is focused on the possible integrating the green building assessment tools into BIM's software data systems.

1. INTRODUCTION

In recent years, considerable efforts have been made to increase energy efficiency and thus reduce energy consumption. On September 2015, the governments of the 193 countries members of the UN signed the "Agenda 2030 for Sustainable Development"[1]. It incorporates 17 Sustainable Development Goals (SDGs) into a major action programme that has set a total of 169 targets. Many of these goals aim to ensure that sustainability friendly patterns are introduced in production and consumption both in the civil and in the industrial sector. To meet sustainability goals and in particular to reduce the buildings' energy requirements, evaluation tools for green buildings (BREEAM, LEED, LCA etc.) are crucial. They suggest actions to reduce the environmental impact of buildings. Having the possibility of applying the actions suggested by the protocols from the very beginning of the design (e.g. of a new building) allows a considerable optimization of the results, compared to applying it backward-looking (e.g. retrofitting an existing building) (Lu et al., 2017). Hence, the most effective decisions on the sustainable design of a building facility are made in the ear-

1 Source: Centro Regionale di Informazione delle Nazioni Unite (Unric) https://www.unric.org/it/agenda-2030

ly design and preconstruction stages. This is not feasible using traditional 2D tools, which require a separate energy analysis to be carried out at the end of the design process. In this case, the windows of opportunity for early modifications of the project to improve the building's energy performance, is limited (Azhar et al., 2009). BIM design process can overcome the problem. It allows to monitor each phase of the construction process (and post-construction) and to integrate sustainability strategies from the preliminary stages of the design (Acampa et al., 2019).

2. ARCHITECTURAL DESIGN: STRATEGIES IMPROVING THE QUALITY

Genuine improvement in the quality of architecture and its construction in this day and age, depends on the abilities of the designers to adopt the entire life cycle of buildings as reference, and on the willingness of all those working in the construction supply chain to establish a virtuous cooperation among themselves (Bertoldini and Campioli, 2009; Bentivegna, 2016).

The issue of cooperation between members of a supply chain affects and, equally, is urgent to achieve new heights of architectural quality and respond adequately to the actual demands that need to be satisfied. This sort of cooperation is becoming increasingly up-to-date, in that the sequential schedule of design and construction activities has now been replaced by skills-matching in real time (Campioli, 2011).

Other issues regarding the quality of the architectural project stem from the awareness rising in many countries of the European Community that the structure and overall quality of the urban and territorial physical space is key for the well-being of the communities living in those cities and territories. It is required to jointly consider on one hand the interacting intrinsic qualities, related to the architectural object, and on the other hand the extrinsic attributes, which concern the object's location in the overall urban and territorial context (Acampa, 2019).

To assess the success of a built and performing work it is a priority to take into consideration the particular balance between its overall performance level and the quantity of resources used to create the work. Yet, this balance must increasingly refer to the whole life cycle (Forte, 2019). This means to assess the resources required for maintenance operations needed to preserve the initial quality, and the resources necessary for its functioning and management (Fattinnanzi, 2018; Fattinnanzi et al., 2018).

Combining the use of the Building Information Model (BIM) with existing green building protocols, could create an optimal strategy to address the issues that we have just introduced.

2.1 BIM as project evaluation tools

BIM is mainly praised for its ability to manage the complex relationship between contracting authorities, contracting companies, and all other subjects contractually involved, turning their joint activity more straightforward, transparent, and systematic.

Besides this significant aspect, it is equally important to stress, that through a totally digitalized design process carried out according to BIM methodologies, considerable amount of information is acquired. If appropriately organized, and processed, this information allows to integrate the evaluation procedures in the decision-making process, enabling a quicker and more detailed control of the works carried out both from a performance and economic points of view (Mondini 2016; Acampa et al., 2020).

In general, switching to BIM design goes beyond simply switching to a new software. The BIM approach requires sharing data among the stakeholders involved in the construction more easily and a willingness to create a partnership with the stakeholders through the digital collection of all information related to the project. Due to the large amount of information included in the single objects, which is peculiar to the BIM process, the resulting model becomes a real "tool" for evaluating the project itself.

As a general rule, the information contained in the model may be treated directly or indirectly; in the first case, the data is processed directly by the software[2], as regarding the detection of interferences (e.g. between structural and plant elements). The second case involves the export of data[3], as an abacus, in order to carry out specific analyses or surveys not supported by the software. In this regard, the InnovANCE[4] research project, financed by the Italian Ministry of Economic Development, is worth mentioning. Its goal is to create the first Italian national database containing all the technical, scientific and economic information useful to the construction industry. InnovANCE will facilitate the integration of all actors in the construction process especially through the use of BIM methodologies, thus avoiding misunderstandings that generate inefficiencies (Motawa and Carter, 2013).

2.1.1 Using BIM for sustainable design

Sustainability is held as one of the basic requirements for

[2] BIM software (e.g. Autodesk Revit or Bentley Aecosim Building Design) makes use of plug-ins that allow them to significantly extend their scope in the field of structural, energy testing etc.

[3] The export of data from the software, usually is possible in digital formats such as .ifc, and .xls

[4] Source http://www.innovance.it/it/; InnovANCE is an Italian project for the digitization of the construction chain financed by the Industria 2015 call for proposals on energy efficiency. The project was promoted by 15 partners, including Ance, Confindustria, University, Cnr, software manufacturers

the development of contemporary society and cities (Amendola, 2016).

The American Institute of Architect AIA[5] defines sustainability as "the ability of society to continue surviving in the future without being forced into decline due to the depletion of the natural resources on which it depends".

In the construction industry, there is a continuous drive towards sustainable design.

To ensure that a project meets sustainability requirements, different software are used to verify energy consumption. These software take into account several factors such as thermal insulation, climate response, solar penetration, natural ventilation, mechanical ventilation HVAC systems, building dynamics and thermal mass (Cho, 2010). If an audit outcome shows that the energy performance of a building is unsatisfactory, the designers will have the chance to modify the design features affecting negatively the building performance. However, any possibility to adjust is limited to the design phase, not taking into account that a building's energy performance could be altered due to its maintenance or operation activities.

From this point of view, BIM allows to reach excellent results in terms of environmental sustainability, but at the same time helps reducing time and costs due to errors or data loss.

In order to obtain the best results from the application of the BIM methodology on sustainable design, Green BIM has been developed. By Green BIM we mean Building Energy Modelling dealing with the project's energy performance; its goal is to identify options for optimising building energy efficiency during its life cycle. At the core of Green BIM processes lies parametric modelling and building simulation tools that support either manual or automated data sharing, and furthermore, multidisciplinary design (de Klijn-Chevalerias and Javed, 2017). It can be deduced that the development of Green BIM depends on the level of interoperability between different software[6].

2.2 Building environmental assessment tools

The construction industry strongly impacts on energy, water, and other raw materials consumption "from cradle to grave". Accordingly, this industry is a main factor in accelerating climate change and depleting natural resources (Macías and García Navarro, n.d.; Darko et al., 2017; Yilmaz and Bakı , 2015). It is globally responsible for 40-50% of the total energy consumption, 30% of the total raw materials consumption, 25% of the total water consumption, 12% of the land consumption, and also generate 25% of the overall solid waste - of which 40% in developed countries (Dong and Ng, 2015).

Reducing the energy requirements and mitigating the environmental impacts of the construction sector has become a key objective for energy policies in various countries. Key players in the sustainable construction industry (Dixit et al., 2013) are called to address environmental and health problems caused by buildings, reducing their impact (Giannetti et al., 2018; Doan et al., 2017).

Currently, several methods exist to certify a building's level of sustainability; they approach the issue from different perspectives and aim to quantitatively and objectively summarise the behavior of the building and its impact.

Since the rise of the first method for evaluating sustainability, in 1975, till today, more than six hundred methods have been developed around the world (Macías and García Navarro, 2010) to evaluate and certify the sustainability of buildings. In the 70's, the majority of methods focused on the use of the life cycle as a reference; in the 80's the analysis of the full life cycle methods was introduced, changing the approach towards the energy and resources needed to build, keep and demolish the building (Dong and Ng, 2015). At the beginning of 90's came out the first multi-criteria systems for evaluating building sustainability. Such systems suggest a series of actions to enhance the environmental sustainability of all buildings across all their life cycles (Vega Clemente, 2015).

There are several methodologies to classify these methods according to their characteristics, structure and common goals (Awadh, 2017). One of them, calls to group them in:

1. Multi-criteria based systems and
2. Life Cycle based Assessments. Below we briefly describe each of them.

2.2.1 Multi-criteria based systems

The multi-criteria based systems are methods to evaluate and certify the degree of a building's sustainability including its (sub)systems. They divide the requisites for sustainable design into categories[7]:

C1) Site suitability development;

C2) Water;

C3) Materials and resource consumption;

C4) Energy;

[5] The American Institute of Architects is based in Washington, D.C. and provides education, retraining and public awareness support to the architect's profession.

[6] The topic is addressed in paragraph 2.2

[7] See table 1

C5) Indoor environmental quality;

C6) Innovation;

C7) Social and economy;

C8) Service Quality;

C9) Circular economy;

C10) Climate changes.

The evaluation process consists in assigning points according to the degree of satisfaction of the criteria set for each category.

Among the methods using multi-criteria evaluations, the most common are: BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design) and CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) [22].

The latter can be applied to new-buildings, exist-construction, and components or parts of a building.

Some of them only have the drive to evaluate or classify the level of sustainability, whereas others go further and allow the certification of the building via a qualified evaluator that has usually been trained by the entity that grants the certification.

BREEAM (Building Research Establishment Environmental Assessment Method), developed by BRE Trust in 1992, is one of the most widely used methods, and the pioneer of environmental certification systems. Initially it evaluated only energetic aspects, but later it was enlarged, and presently it takes into account a wide range of ecological, environmental and health factors (IHOBE, 2010).

LEED (Leadership in Energy and Environmental Design) created by the Green Building Council of the United States (USGBC) in 2000, is a worldwide recognized evaluation system. The LEED certification scheme has become a reference system for the design, construction and operation of green buildings beyond USA. Like BREEAM, it is based on the allocation of points or credits according to the fulfillment of the criteria of each category.

In recent years, the LEED Protocol has been increasingly used in Italy as well. According to data released by GBC Italia[8], 441 buildings are now certified and registered using LEED with a total surface area of about 5.3 million square meters[9].

A famous example in Italy concerns Palazzo Ricordi located in Milan (certified LEED Core&Shell Gold level) that was subject to major renovations that involved the structure, the shell, the internal distribution and the entire system of heating, cooling and ventilation (HVAC). The certification for Palazzo Ricordi has arrived at the end of 2014. The new building, in class A, saves over 35% of energy consumption, reducing CO_2[10] equivalent emissions by 40%.

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) (Haapio and Viitaniemi, 2008) is the first environmental assessment method for buildings developed in Japan for the promotion of sustainable buildings. It was issued in 2002 and formerly called DfE (Design for Environment). CASBEE is used by architects and engineers in the design process and may work as a design support tool as well as a self-checklist. It makes assessments based on the design specifications and the anticipated performance.

2.2.2. Life Cycle Based Assessment system

The Life Cycle Assessment tools (LCA) are standardized methods (using ISO 14040 as reference) to assess the global environmental impact of a product or service. Instead of considering only a specific part of the life cycle, LCA methods analyze the complete environmental impact of a product/service, from the extraction and manufacture of its raw materials, to its operation and disposal (Cole, 2006).

These assessment tools are not geared towards certification, classification or compliance with sustainable minimum requirements, but towards supporting the professional for the sustainable design of a building. The aim of most of them is to ease the choice among various options in design, building materials and local services during the design phase (Evaluaci, n.d.; Díaz López et al., 2019). LCA methods can not only be applied to assess the environmental and energy impacts of the building's life cycle, but also to compare two buildings with the same function and measure their sustainability (CASBEE, n.d.).

Among the methods based on LCA assessments we find:

- BEES 4.0 (Building for Environmental and Economic Sustainability) developed by the U.S. National Institute of Standards and Technology (NIST) in 2007, which measures the environmental performance of construction products using the environmental life-cycle assessment approach specified in ISO 14040 standards (Asdrubali et al., 2013). It provides an integrated package for the economic and environmental assessment of a wide range of building materials.

[8] Green Building Council Italia: is a non-profit association that is part of the international network of GBCs operating in many other countries; Thanks to a partnership agreement with USGBC, GBC Italia adapts to the Italian situation and promotes the independent certification system LEED® Leadership in Energy and Environmental Design whose parameters establish precise criteria for the design and construction of healthy, energy efficient and environmentally friendly buildings.

[9] Source: GBC Italia year 2017

[10] Source: http://www.green.it/protocollo-leed-in-italia

- BEAT 2002 (Building Environmental Assessment Tool) is an LCA based inventory and assessment tool developed at the Danish Building and Urban Research. It is targeted specifically at the building industry for the environmental assessment of building products and buildings (Martínez-Rocamora et al., 2016).
- EcoQuantum, developed in the Netherlands in 1999, which aims to define the environmental performance of buildings during their life cycle and to assess the ecological efficiency of different design alternatives (Hernandez et al., 2019; Lippiatt, 2007). This method evaluates the environmental performance of a building and uses the gathered data to calculate four sets of indicators:

  1) consumption of raw materials;

  2) emissions;

  3) energy consumption;

  4) waste.

  To comply with the evaluation process, each indicator is scored according to the project's goals (Al-Jebouri et al., 2017).

2.2.3. Relationship between methods and categories

Once classified and described various evaluation methods, our next step is to compare them. Table 1 shows the relationship between each of the methods and the categories it considers (Chandratilake, 2015). As we can see, the multi-criteria based systems (BREEAM, LEED, CASBEE) cover the highest percentage of categories. LEED, with its latest updates, is the only one to analyse all of them. Regarding environmental aspects, the categories Energy (C4) and Quality of the interior environment (C5), are considered in all the methods studied (BREEAM, LEED, CASBEE, BEES 4.0, BEAT 2002 and ECO-QUANTUM), showing these aspects of sustainability are more easy to evaluate, compare to the social and economic aspects covered in more recent software.

3. INTEGRATION BETWEEN STRATEGIES

3.1 BIM's software data system

To fulfil the purpose of this study (i.e. the possible integration of the green building assessment tools into BIM's software) it is important to understand how these software data system work.

For this reason, we analysed the data systems of two different BIM software, AECOsim Building Designer or ABD[11] (vers. 10.02.00.35) and Revit 2018, respectively owned by Bentley and Autodesk. Looking at the ABD data management process, all sensitive information both quantitative and qualitative are distributed in two complementary and associated environments, the DataSet and the DataGroup (Fig. 1).

The DataSet contains all the information concerning the display and computation functions. It is divided into Parts and Families[12]. The DataGroup represents a real catalogue storing all the information concerning BIM objects. Moreover, the default cards in the DataGroup can be modified or added as needed.

Revit software has a completely different structure. The composite structure of DataSet / DataGroup, typical of ABD, is essentially translated within the Families (Fig. 2).

Their organization is divided into main macro categories called System and Loadable.

System families include all the basic elements used in a construction process. They are customizable within certain limits[13] pre-set by the software (Holleris Petersen, n.d.).

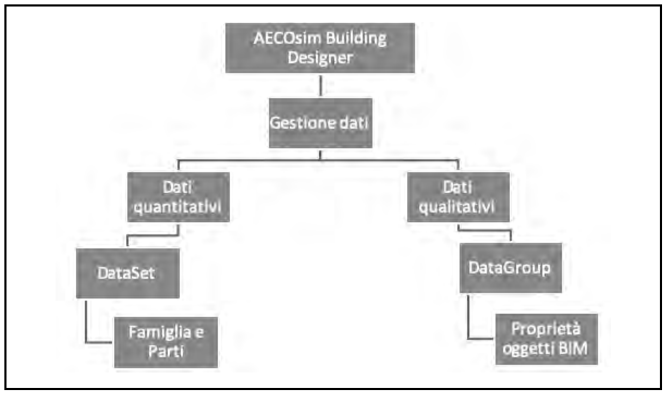

Figure 1 - *ABD structure*

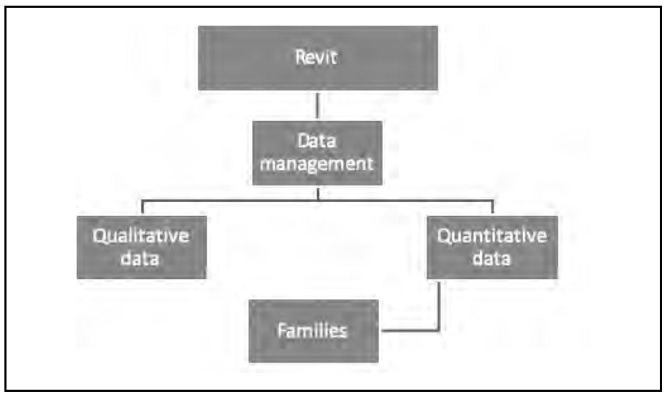

Figure 2 - *Revit structure*

[11] Below will be abbreviated with ABD.

[12] Families are defined as a "group of elements with a set of common properties known as parameters and an associated graphical representation". This definition can be considered valid for both software mentioned in this case study.

[13] Limits are set to exclude changes that could compromise the correct functioning of the family.

Table 1 - *Reletionships between categories and methods*

Categories	Criteria	AMC			LCA		
		BREEAM	LEED	CASBEE	BEES 4.0	BEAT 2002	ECO-QUANTUM
(C1) Site suitability development	impacts related to the planning, design, regeneration and influence of the characteristics of the site; transport management and external light pollution	•	•	•			
(C2) Water	performance, cycle, use and monitoring of the various water sources	•	•	•	•		•
(C3) Materials and resource consumption	use, recycling, reuse and environmental impact of materials and resources	•	•	•	•	•	•
(C4) Energy	reduction, control, consumption and use of energy	•	•	•	•	•	•
(C5) Indoor environmental quality	environmental ergonomics	•	•	•			
(C6) Innovation	designs, processes and strategies that promote sustainability in the built environment and building	•	•	•	•		
(C7) Social and economy	use of traditional local materials and techniques, design compatible with cultural values, the cost of use and commercial viability	•	•	•	•		
(C8) Service quality	efficiency in the use of the spaces, the capacity of local control of the different systems, and the efficiency of an adequate management and maintenance plan	•	•	•			
(C9) Circular economy	use of resources and reuse of building materials, systems and subsystems	•	•				
(C10) Climate changes	ability of buildings to adapt to climate change and its consequences without incurring damage		•				

Instead the Loadable families aren't defined by default and can be loaded from external libraries. They are also customizable in terms of shape, composition, appearance and object's parameterization.

3.2 Integrate green building assessment tools into the data system

Information and exchange are the core and key activities of BIM, but it is not unusual that stakeholders engaged in the same project use different software, especially when their roles require the use of unique features of specific applications. In building design, the direct impact of this heterogeneous environment is loss of productivity. It is as the project team members speak different languages without having an interpreter. Therefore, communication is severely handicapped, critical project information and data fail to be accurately disseminated. Interoperability responds to the need to share data between applications, allowing multiple types of experts and applications to contribute to the work at hand via a format defined on purpose.

Major exchange formats for interoperability are (Acampa et al., 2018):

- Direct, proprietary links between specific BIM tools;
- Proprietary, file exchange formats dealing primarily with geometry;

- Public product data model exchange formats (IFC and CIS/2);

and

- XML-based exchange formats.

Nowadays, IFC and CIS/2 are the only public and internationally recognized standards. As CIS/2 use is limited to the steel fabrication sector, the IFC[14] data model is likely to become the international standard for data exchange and integration of the building construction industries. It was designed to deal with all the building's information (including that related to building performance and sustainability), over the whole building's lifecycle, from feasibility and planning, through design (including analysis and simulation), construction, occupancy and operation. We stress that IFC is not the data per se, but an exchange format that could facilitate data exchange between different software applications.

To understand if BIM software and green building assessment tools could really "talk to each other" it is important to answer two questions:

1. What does the LEED rating system and certification require?
2. What solution can BIM provide?

First of all, we choose to refer to the LEED rating system because, as showed in Table n.1, it is the only one that takes into account all the categories (C1 to C10), from site sustainability to the climate change. Thus, we may fully evaluate the possibilities of integrating all categories of criteria within a BIM software data system, by looking just at LEED.

Now we may answer the previous questions:

1. *What does the LEED rating system and certification require?*

As described at point 1.2.1, LEED rating system assesses the environmental performance of buildings from an overall point of view during their entire life cycle, starting from the design phase and during the construction and operation. The number of points the project earns by meeting the criteria set in each category, determines the level of the certification. There are four progressive levels of certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80 points or more) (Eastman et al., 2008).

2. *What solution can BIM provide?*

To understand how efficient the integration between LEED and BIM can be, a proof-of-concept survey was conducted by W. Wu et al. (2017). The aim of the survey was to collect AEC professionals' opinions about the feasibility in terms of technology and operation, of integrating BIM and LEED[15]. In particular, it investigated the participants' opinions on how applicable are current BIM solutions to help achieving LEED certification, carried out the analysis at a credit by credit level. The scores were: 0 not applicable; 1 hardly Applicable; 2 Somewhat applicable; 3 Moderately applicable; 4 Applicable; 5 Highly Applicable (Wu, 2010).

The survey showed that among all the categories (C1 to C10), the ones that obtained the highest score were C5 "Indoor Enviromental Quality" and C8 "Service Quality" (Table 2). They relate to the most common aspects considered when using BIM design process. Therefore, all the available BIM software (as the Autodesk Revit) allow to implement these categories to the design process without the need of plug-in or IFC export format.

As for all the other categories, which are not immediately supported by BIM software functionalities, one of the following the two approaches should be followed:

- retrieve needed external information from other incompatible applications using IFC and XML exchange formats;
- use new applications developed by the BIM software houses to support designers in setting the buildings performances on energy efficiency, indoor air quality and other important environmental benchmarks. Examples of such applications are Autodesk Green Building Studio (GBS), an Autodesk Revit plug-in[16] for energy simulation, daylighting and water consumption calculation; and Bentley AECOSim for ASHRAE 90.1[17] regarding LEED Energy baseline simulations.

Driven by policies, incentives, and the setting of green codes and standards, sustainable design has reached an unprecedented level, and with the development of new plug-in by software manufacturers, it is expected to still grow in the future.

[14] Industry Foundation Class (IFC) is an ISO standard (ISO/PAS 16739) for exchange of construction data.

[15] The survey was deployed at Zoomerang.com (a web-based surveying service) from June 30th 2017 to August 1st 2017. A total of 35 completed questionnaires were obtained out of 190 participants, who were AEC professionals in the U.S. market.

[16] Autodesk Green Building Studio is cloud software that allows to simulate building performance in order to optimize its energy efficiency.

[17] ASHRAE was established as the American Society of Heating, Refrigerating and Air-Conditioning Engineers by the merger in 1959 of American Society of Heating and Air-Conditioning Engineers (ASHAE) founded in 1894 and The American Society of Refrigerating Engineers (ASRE) founded in 1904. ASHRAE 90.1 is a standard provides the minimum requirements for energy-efficient design of most buildings, except low-rise residential buildings. It offers, in detail, the minimum energy-efficient requirements for design and construction of new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements.

Table 2 - *LEED categories and BIM Implementation*

LEED Categories	High Mean Score	Low Mean Score	Average Mean Score
(C1) Site suitability development	3.34	1.94	2.68
(C2) Water Efficiency	2.78	2.44	2.60
(C3) Materials and resource consumption	3.44	2.16	2.69
(C4) Energy	3.78	2.31	2.99
(C5) Indoor Environmental Quality	4.15	2.20	3.18
(C6) Innovation	3.68	1.83	2.76
(C7) Social Economy	2.32	2.32	2.32
(C8) Service quality	4.50	2.60	3.55
(C9) Circular Economy	4.13	2.10	3.03
(C10) Climate change	2.60	1.85	2.22

4. CONCLUSIONS

In order to improve the quality of architectural projects, we believe that it is crucial to integrate two systems: BIM – to digitalize, present and simulate the project, and LEED – to evaluate and certify green building.

In order to understand how this integration process could take place, we analysed the results of a survey conducted by Wu et al. in 2017. It turned out that the integration process is being slowed down by the fact that only 2 of the existing 10 categories of criteria set by LEED can be easily assessed by a BIM software.

Interoperability is a bottleneck too, that limits the development of the integration framework, given that information exchange is the key issue in project management.

A huge setback in current interoperability frameworks such as IFC is the lack of ontology and semantics to describe the vocabulary of sustainability in a format that can be read and understood by computers. Meanwhile, popular BIM software poorly support interoperability at database level.

Nevertheless, we believe that the continuous evolution in software and the rising call for formats standardization may improve the current situation.

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