BIM Technology in Green Buildings: Integrating BIM with Greenery Systems

Mitra Manouchehri, Mercedes Valiente López, and Joaquín Santiago López

Abstract The importance of Building Information Modelling (BIM) in achieving sustainable goals is well recognized in the global construction industry. Several studies on BIM have been conducted in the past decade. However, a considerable gap exists regarding the integration of BIM with greenery systems. Greenery infrastructural systems provide a great opportunity in this respect by connecting buildings to the urban environment thereby integrating greenery into increasingly densely populated cities. They may also influence microclimate conditions and contribute to enhancing life quality in urban spaces in various ways. It is to be expected that greening of the building surfaces will be mandatory in an increasing number of cities in the future, in the form of converting a specific area of the building's facade into green space. In this context, the simulation can be used to carry out the obligatory planning of the facade greening. The integration of the concepts of greenery systems and BIM technology could promote the digitalization process in the building sector by offering solutions to improve environmental quality whilst reducing costs. This study explores ways in which BIM and greenery systems can be integrated through an analytical review of evidence from both academic research and case studies; it will also address present challenges towards this green development. In addition, the most significant simulation factors for modelling existing greenery systems and their associated key performance parameters will be analysed and prepared for application in BIM tools. This research could provide great potential by simplifying the decision-making process for the implementation of greenery systems in buildings and can therefore serve as a crucial interface to guide building and greenery researchers and practitioners.

Keywords Building Information Modelling (BIM) · Greenery systems · Buildings · Decision-making process

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1 Introduction

The Architectural, Engineering, and Construction (AEC) professionals and industry researchers, as well as policymakers, have agreed on the positive influence of the development of greenery systems to overcome the rising concern about global warming caused by the extreme growth of urbanization.

The greening of the building envelope has been formerly used as an aesthetic and protective feature in buildings. However, the concept of greenery systems has been introduced and promoted extensively over the past years. Greenery systems stand out amongst the wide range of passive and low energy building systems available, and they are responsible for incorporating vegetation into architecture on a massive scale. The current technology used in these systems can contribute to sustainable improvement in the building industry. It can also increase the functional benefits of plants to the building performance level [1].

The terms Greenery Systems, Greening Systems, Green Infrastructural Systems, and Building Integrated Vegetation (BIV) are often used in this context. Building-integrated vegetation is formed by green roofs and vertical greenery systems applied to both exterior and internal walls. The existence of vegetation means roofs and walls are living systems that breathe. Thus, the vegetation is encouraged to develop a relationship between concepts of nature and the built environment [2].

Green roof is an established technology in the construction sector, and public and private stakeholders are recently growing more interested in vertical greening systems. The reasons are not only related to their ability to create unique patterns over the building envelope, but also clear energy and environmental benefits. Vertical greenery systems are subdivided into two main categories: Green Facades and Living Wall Systems (LWS). There is a further distinction between green facades and LWSs. As in green facades, climbing plants grow along the wall covering it, whilst LWS is a more recent concept which includes materials and technology to support a wider variety of plants that create a consistent growth along the surface. In LWSs, plants receive water and nutrients from vertical support instead of from the ground. Despite the fact stakeholders recognize the benefits of vertical greening systems, there are some obstacles for large-scale deployment, one being the lack of a consistent standardization to assess their performance [2].

To counteract climate change, big cities are promoting buildings with greenery systems. A good example is the Santalaia building in Bogotá. According to the design team, this green wall can provide oxygen to more than 3000 residents and clean up the equivalent of carbon emissions produced by 745 cars. Bogotá has a temperature ranging 3°–4° higher in areas of higher urban density. The adoption of greenery systems contributes to reducing the urban heat island effect that exists in the urban area compared to the suburbs [3].

Another revolutionary technology proposed as an innovative solution in a wide range of AEC research projects is Building Information Modelling (BIM). BIM emerged as a solution to promote the integration and management of information throughout the building life cycle by offering the possibility of making the best use of the existing design data for sustainable goals and performance assessment. Since both BIM and green building are gathering momentum, an increasing number of AEC companies are beginning to develop technology on “green BIM” [4].

One famous example of the use of BIM technology is in the Disneyland buildings in Shanghai. In order to keep users safe and protect the environment, over 70% of the buildings were developed using BIM tools. The application of BIM technology gave the project teams access to the same resources and support, and at the same time offered extra advantages such as reducing work, sharing models, increasing the level of details in the design, and thus keeping timelines and objectives [5].

The application of greenery systems in architectural projects has grown substantially over the last few years, but their implementation has little to do with computational control methods or design. It is necessary to integrate the greenery system within BIM tools to overcome the limitations of the potential green architecture. Various research papers have suggested the benefits of greenery, ranging from creating a conducive environment for social activity, promotion of positive effects on mental health, acoustics dampening, to the cooling of the surrounding microclimate. However, literature reviews show there is limited research regarding the incorporation of BIM into the creation stages of greenery systems [6].

In this chapter, we delve into how BIM is applied in greenery system projects and the reasons for its apparent lack of use. Moreover, we discuss the possibility of modelling facade greening systems using BIM tools. Next, we search through the important criteria and factors that should be considered in the application of BIM in greenery system design and simulation stages. And finally, we gauge the advantages and limitations of BIM integration into greenery systems.

The research focus is on the existing greenery systems in Madrid, Spain. To this purpose, we studied the landmarks of facade greenery systems in Madrid landscaped over the past years. Research demonstrates there is no specific BIM implementation in the design and construction stages of these greenery systems. Additionally, results from the systematic analysis of the samples clearly show the limited use of BIM in the development of greenery systems. Moreover, influential factors in the design and other important aspects of the greenery systems simulation are discussed to identify challenging areas and thus facilitate BIM use in the greenery design.

As we have explained above, the combination of BIM and the digital planning process in this field has received little attention. This chapter presents and evaluates the existing approaches towards the integration of BIM and Green Infrastructure Systems and their implications for urban development in the future.

2 Background and Literature Review

2.1 Building Information Modelling (BIM) Technology

The concept of sustainable development was first introduced in 1987 in the World Commission on Environment and Development's Brundtland Report to align economic development with social and environmental balance. Since then, various efforts have been made in support of this concept. Various commissions have been organized and the European Union (EU) has ever since launched different plans to move towards sustainability [7].

BIM was presented as a viable solution to achieve sustainability goals. BIM technology, as an innovative approach that includes diverse tools, can effectively evaluate energy performance in urban facilities. The application of BIM assists in the conversion of two-dimensional drawings into three-dimensional visualization renderings and also can provide architectural information about the building life cycle [8].

The use of computer technology can significantly contribute to facilitating and improving the result. The development of an architectural information model provides technical platform support for all project participant units to share the essential information of the project at all phases, so that different experts, such as design department, construction units, facility operators and operation and maintenance units can work collaboratively on the BIM 3-D model [9].

BIM technology can generate virtual environments identical to real work situations; hence it could detect potential problems at the earlier phases of the project. In construction projects, BIM can serve as a comprehensive method that can enhance performance, preserve practical resources; lower building costs reduce design discrepancies and optimize architectural design procedures to obtain sustainable results. BIM contains a complete process of information modelling including the ongoing technological development, as well as the incorporation of simulation and virtual technology based on parameterisation and computerisation of traditional architecture [9].

A BIM model could comprise individual 3-D models of each building component, with all associated properties such as weight, material, length, height. Beyond the inherent information, BIM also includes external associations between building components. BIM has been applied in the areas of structure, energy, disaster prevention, construction planning and scheduling, project control, construction safety, and maintenance [10]. Amongst the advantages of using this technology, we should mention clash detection in early design stages, automatic design regulatory inspection algorithm and Augmented Reality (AR) visualization to improve the productiveness of on-site work. Moreover, BIM provides a collaborative work environment [11].

Because of the fast growth of BIM in the AEC industry, both at academic and professional level, new approaches based on BIM have been proposed to address the needs in this area. For instance, Building Energy Modelling (BEM) is a tool for energy analysis that can be used with BIM programmes and allows experts to simulate and analyse energy processes in buildings to further improve energy performance through modelling parameters such as heating, cooling, ventilation, lighting, and plug and process loads as well as water use in buildings. The experts believe its application will increase soon due to its ability to provide a high return on investment and improve sustainability standards [12].

Another approach to the application of BIM in buildings is Historic Building Information Modelling (HBIM). This term involves a new way of modelling existing buildings based on a BIM process that would produce intelligent models containing and managing information. Such models pertain to project components and include their geometric and identifying features, as well as all the physical properties that best describe them. HBIM was designed to generate a BIM model of historical and monumental buildings including a database of model information such as simple geometric reconstruction of volumes or thermal analyses to be inserted into the simulation tools. The application of HBIM was later extended to all existing building models, not only in terms of digital and geometric 3-D reconstruction, but also as a method involving intelligent models with added information. More specifically, this technology can replicate an existing building in order to provide a more feasible way for upgrading its features [13].

The information types in BIM tools are divided into three major categories according to Schlueter and Thesseling [14] research, namely, geometric, semantic and topological. Geometric information shows the 3-D modelling of a building, and semantic information includes the properties of components. Topological information describes the dependence relationship between properties and components [10]. In the present research, we consider all these three types of information for the definition of influential parameters.

BIM adoption in many countries such as the United Kingdom is going from being led by innovators and early adopters towards becoming a more mature market. There is also academic research on adopting BIM in other countries such as China, Finland, Iceland, and India [15]. Regarding Spain, no such project had been undertaken until 2017 [15].

In 2017, the QBIMInvest project [15]—supported by the Universidad Europea de Madrid—conducted a survey on the implementation of BIM in the Spanish AEC industry. The study showed that BIM tools are being used in the design phases. However, the use of BIM tools in the construction stage is insignificant and the BIM model of the project is not generated until it has become a model developed solely for operation and maintenance purposes. It should be highlighted that these are the phases that profit most from the utilization of these tools [15].

Additional challenges of BIM implementation are associated with software and hardware issues. Interoperability is one of the problems in the AEC industry. The former problem happens because dynamics and adaptability are necessary to work in this sector and that users often use different applications and systems [15]. The existing technical issues and interoperability problems between different BIM software packages will be hopefully solved by the package providers over time. Nevertheless, it is more complicated to solve issues regarding people's agreement on common IT platforms and cooperation to share their BIM data models. Restrictions on data flow towards and from other parties is another key problem, especially as far as license and intellectual property ownership of BIM-generated output is concerned [15].

Overall, the importance of BIM is widely known today. Alongside the importance of cost–benefit analysis, more awareness-raising and up-skilling in the sector are required. Hence, senior managers in building companies will need to invest in BIM education and staff training. Apart from existing general limitations that hinder BIM employment, timelines, levels of expertise and cost also remain barriers to BIM adoption. Moreover, there is lack of transparency in the industry and many practitioners are uncertain about claims to the application of BIM in new and existing projects [15].

2.2 *Overview of BIM Software Programmes*

Since BIM is widely used around the globe, there are many options for the software available today. Some of the most widely used BIM software in the AEC industry are Autodesk Revit, ArchiCAD by Graphisoft, Autodesk BIM 360, AECOsim Building Designer for Bentley Systems company, Allplan Architecture, BIMobject, IrisVR, Navisworks, ACCA software Edificius, Tekla BIMsight, Tekla Structure; Trimble Connect, Vectorworks Architect and Rhinoceros VisualARQ. Each of the programmes mentioned focuses on one aspect since the BIM environment is highly open to developer implementations and interpretations. For example, the Tekla Structure is oriented to structural projects, and Vectorworks focuses on architectural rendering and interior design [16].

Amongst the existing BIM programmes, Autodesk Revit and ArchiCAD are the leading ones. These software tools have extensive 3-D object libraries and attribute tables containing useful information to help through the design, construction, and maintenance stages. Objects in Revit contain physical parameters and analytical properties. However, these tools do not provide intelligent plant libraries containing plants' attributes, environmental factors, or their relationship to the environment, which could help designers and planners understand the plant-environment relationship and manage that information in a BIM environment [6].

The existing plant families in REVIT include the geometric components such as height, which only reflects a fully mature plant, whilst the rest of properties such as appearance, model, manufacturer, and cost, are like any other building component. ArchiCAD offers the possibility to alter more geometric properties like height and diameter, and plants can be selected depending on the real-time site conditions. However, critical environmental factors such as light, temperature, and spacing are not considered. Comparably, Vectorworks BIM introduces some additional parameters, however they are not enough to support through BIM design process [6].

Furthermore, a number of plug-ins has been developed for specific BIM authoring software to address the existing issues of plant-based modelling. These include

CS ArtisanRV, ENVIRONMENT plugin for Autodesk Revit, Lands Design for Rhinoceros and Autodesk AutoCAD, and Land F/X for Autodesk AutoCAD. In addition, Vectorworks developed a variant called Vectorworks Landmark specifically for greenery and landscape design. One important limitation of these solutions is the need to subscribe to one particular software, preventing a conformed practice at the national level with a centralized database [17].

Considering the existing limitations, various research approaches present their work through the Industry Foundation Classes (IFC) standard for data exchange regardless of the BIM authoring software used, which provides architects with a more efficient means for creating and using a unified vegetation library. The benefit of a neutral information format is the reduction of the problems that may occur when information is exchanged and converted to a different format. Furthermore, all the units involved in a project can choose to use the BIM software they prefer, as long as the software supports the IFC interface [18].

2.3 Standards and Regulations

Standardization is growing continuously in the BIM area, as it is considered a key factor in an industry with such a high and diverse number of agents. In 2014, the European Union (EU) urged countries to consider the need for BIM technology to improve public procurement processes. The European Parliament advised the Member States to address modernizing procurement regulation and public tenders. Currently, many countries in the EU, including Spain, have implemented BIM strategy at the national level, thus promoting the demand for the use of this tool in public projects [19].

Governmental bodies in Spain have decided to take the lead in the process of adopting BIM methodology throughout the infrastructures' life cycle. Specific actions involve monitoring public administrations to adopt BIM criteria in infrastructure tenders, drawing a roadmap to adopt the regulations for general use, and developing national standards that allow widespread adoption [19]. The Spanish construction industry has been subject to EU Directive 2014/24/UE. This directive allows member states to encourage, specify and even require the use of Building Information Modelling (BIM) in construction projects financed by EU public funds as of 2016 [15, 20].

Since 2009 individual attempts to incorporate BIM processes as required in international projects were undertaken in Spain by some companies. However, it was only in December 2018 that the use of BIM became mandatory for public building tenders [20, 21]. Making the use of BIM mandatory was a milestone towards a more digitalized construction industry. According to the reports published by the European Commission (EC) in March 2019, 75% of companies that adopted BIM reported a positive return on their investment with shorter project lifecycles and savings in paperwork and material costs [22].

As regards standards and regulations, there have been several committees and organizations in charge of providing comprehensive data and regulations for AEC in Spain over the last years:

The International Committee, ISO/TC 59 Buildings and Civil Engineering Works, works on the standardization of BIM methodologies. There is also a European Committee, CEN/TC 442 Building Information Modelling, whose scope of application is life cycle standardization for the built environment in the field of structured semantic information [22].

The Spanish Association for Standardization, UNE, has been working since 2011 on the standardization of BIM activities. UNE is a subdivision of AENOR, designated to carry out standardization activities nationwide (UNE standards) and to take part in international standardization procedures (EN and ISO standards). The Subcommittee on Organization of information models related to building and civil works was created in the same year. This subcommittee, chaired by a representative of the Building Smart Spanish Chapter and whose secretariat is held by Spanish Institute of Cement and Applications (IECA), includes 40 entities belonging to both the industrial and research fields. The subcommittee regularly collaborates with international counterparts [22–24].

In 2014, the BuildingSMART Spanish Chapter Association was officially set up to promote BIM through open standards. Additionally, a standardization initiative called uBIM was proposed within the framework of the EUBIM 2013 Conference. The initial objective of uBIM was to develop a guide in Spanish for BIM users. This document was designed to be accessible so as to provide constant support, and to ensure effective actions are taken in the sector. The first 13 documents that make up uBIM guide have been adapted from the Finnish COBIM (Common BIM Requirements 2012) prepared by BuildingSMART Finland in 2012. The development of this guide has been carried out collaboratively with the participation of around 80 independent professionals [25].

In 2015 the Ministry of Public Works established the esBIM Commission. It was made up of different agents and organizations belonging to both the public and private sectors in pursuance of European Directives in Spain. The esBIM draws periodic reports on the progress of the BIM strategy in the Spanish context. In 2015, The EUBIM-Spain Conference was held in Barcelona, where several Catalan institutions outlined the current situation in terms of initiatives to promote the nationwide use of BIM. In May 2016, the Interdepartmental Commission for BIM implementation in public works was set up and later in 2017; IFC standards were adopted for spreading BIM processes in all phases of the construction process [21].

The Spanish versions of the UNE-ISO 19650-1 and UNE-ISO 19650-2 Standards set the principles for business processes in the construction sector. This standard specifies the requirements for information management in the form of a management process in the context of the asset development phase and the information exchanges within that phase, using building information modelling. This document can be applied to all types of assets and all sizes of organizations, regardless of the procurement strategy chosen. The National Committee is currently working on the adoption of the PNE-EN ISO 16757-1 Standards Data Structures for electronic catalogues of products for construction services [22].

It seems clear that intelligent facades, including greenery wall systems, could be one of the options to generate a dynamic and clean urban context. Considering the existing standards and regulations towards BIM adoption and their evolution, it is possible to track down the application of BIM in buildings with greenery systems to analyse the development of their design and function over the past decade.

2.4 The State-of-the-Art in BIM and Greenery Systems

Integrating vegetation into the built environment can mitigate the negative effects of growing urbanization. In recent years in countries like Singapore and Austria, government policies support the inclusion of sky-rise greenery into new and existing buildings whilst constitutional BIM submissions in AEC industries have been promoted. However, landscape projects are still excluded from these BIM submissions due to the absence of an organized database for vegetation and the lack of a unified BIM platform for greenery structures [25, 33].

As the demand for greenery systems is increasing due to the growing demand for climate resilience in cities, a false branding image of sustainability may be accompanied by such architectural claims. "Green-slapping" is a term devised by Allan et al. to describe the overuse of green systems, whereby buildings are overloaded with greenery to produce an illusion of sustainability, whereas the project's specifications do not support its sustainability claims [26].

The application of a 3-D information model for plants lies on a quite different level from the information modelling of the buildings. The parametric factors of a plant contain a huge amount of data due to the plant being a natural element. Plants foliage does not react quite like a solid wall surface, as they are not always in a fixed state and their element properties are constantly changing due to factors such as constant growth or external factors like wind and light [27]. Considering the existing differences and limitations, in this study, the term "Greenery Information Modelling" (GIM) is proposed for the process of 3-D information modelling of greenery systems.

The usual complexity of 3-D models with regards to plant materials is further pursued by the lack of a comprehensive material database for greenery system-related 3-D models. Whilst there are usually predefined settings for architectural components like concrete, masonry, or timber materials, there is little systematic information concerning plant materials. Existing vegetation libraries within BIM authoring software are either too limited in terms of species variety or lack specific species. Although it is possible to customize vegetation models or adopt third party libraries in certain software tools, the need to do research and establish various parameters to better define the materials requires additional time and effort to question its practicality for the designers. Without any governing BIM standard, it might not be possible for an extended period [17, 27].

For example, the National Building Specification (NBS) National BIM Library of the United Kingdom, which hosts thousands of BIM objects according to the NBS BIM Object standards, does not comprise a single plant object, whilst other online libraries with individually modelled trees and shrubs are limited to a small number of pre-generated species [17].

At present, Singapore has a centralized public vegetation library maintained by the National Parks Board (NParks) Flora and Fauna Web (FFW). The library contains exceptional botanical details of over 4000 plant species; however, it lacks spatial information. Along the same line, it is to be expected that the FFW database, or other similar vegetation databases, can be extended to include more spatial attributes to generate specific 3-D BIM vegetation models for the industry [17].

Another example is the workflow proposed by Gobeawan et al. [17]. They introduced a methodology in the context of Singapore also applicable to other cities given their species spatial parameters obtained by field measurements or observations. They produced lightweight simplified BIM vegetation models for a computationally efficient means to model these objects with special attention to trees and shrubs. Their workflow comprises four interrelated modules, namely, the vegetation library compilation, BIM authoring workflow, IFC interface, and 3-D vegetation model generation.

Other researchers have also contributed to shed light on the relationship between BIM and greenery systems. The next paragraphs provide highlights of their work:

Krygiel and Nies [28] claim that the goal of BIM is to provide an endless range of possibilities targeted to a design project through a combination of functionalities. They developed a BIM roadmap to show the connection between such features and their functions. They believed the core idea behind BIM is to digitalize the ongoing and interlinked construction process, incorporating all the segments, from design to construction and details like building services and landscape. However, in the case of greenery systems, the omission of greenery is a common occurrence during the digital design model process [26].

Allan and Kim [26] studied the extent of accuracy and efficiency of sustainability claims that BIM can provide during the digital process of vertical greenery design. They established the feasibility of applying vertical greenery systems as part of the BIM process to assess building performance during a project's design stage. The intention was to advance tropical architecture alongside technological improvements in building design.

Briscoe [29] analysed a design process that stems from an extensive green wall pilot project along a 260' × 70' west-facing parking garage facade in Austin, Texas. The project team charted viable precedents and commercial products of both living and facade modular applications and included current parametric, modular plant, and habitat research and they further explored factors at the scale of landscape and of material for formal pattern making and instantiation.

Izlam et al. [27] investigated the possible workflow for architects and architectural engineers to incorporate digital simulation-based energy performance analysis in the design of living wall integrated facades. Their study focuses on living walls (the plant, substrate, and structural support are directly integrated within the building wall).

According to a study conducted at the Queensland University of Technology [30], choice of vegetation type, substrate geometry, facade orientation aspect, and other factors can negatively influence the energy consumption outcome of vertical greenery system (VGS). The studies also reveal the importance of considering Leaf Area Index (LAI) in plant selection. LAI represents the amount of leaf surface area per unit of wall or ground area and allows to measure the vegetation and different plant canopies effects [26]. Furthermore, the research shows that plants with greater LAI (typically larger than four) can contribute to more significant savings than plants with LAI lesser than two. This fact may produce an adverse effect and instead consume more resources like water and energy [26].

The study by UMD shows that the amount of cooling, heat flux, and reduction in environment temperature provided by a green facade is directly related to the amount of leaf area present in the VGS. Therefore, in order to conduct greenery systems simulation studies in BIM, the acquisition of LAI data is a necessary step [26].

Allan and Kim [26] also claim in their study that a difference of two centimetres within a plant growing average thickness can cause drastic variations in the result of energy savings (from 2 up to 18%). Hence, it is important to consider this for BIM simulation in large-scale tropical architecture projects. Greenery systems without well-considered design parameters may not only fail to achieve their expected sustainable values but also requires additional energy and maintenance costs.

Previous studies based on cost–benefit analysis of greening systems indicate that since the effects of greening are complex and manifold on different levels on groups of people and areas, consideration of private costs and benefits is not sufficient to reflect the actual value of greening. They also show that additional criteria need to be considered in the future assessments for us to be able to make general statements about the actual profitability of the systems [31].

Besides, there is scarce evidence to predict the success of greenery systems prior to the design phase, during construction and even after the project completion. Currently, it is only after a specific amount of time conducting to the growth and maturity of plants that the success or failure of the project can be evaluated, so it is important to note that design decisions can significantly impact energy consumption levels [26].

Despite the progress made in green architecture over the last years, the implementation of greenery systems remains on a superficial level of aesthetics. Most greenery system projects to date are showpieces devised to create an outstanding installation with a positive image [22, 27]. There is a lack of established simulation tools for quantitative analysis of design. Most of the studies on thermal benefits are experimental or mathematical model-based, and not suitable for architects and designers. The findings of scientific studies are rarely combined with digital design platforms such as BIM or 3-D modelling to specifically test in the building context [31].

Furthermore, for greenery systems, there is insufficient advancement concerning BIM utilization that would support decision-making. To integrate the present greenery systems into future planning methods of sustainable cities and continue the digital development in the construction industry, integration of these systems into BIM is needed, and appropriate methods to implement automated planning should be adopted.

To consider the diverse influence of greenery systems, various criteria must be considered. Thus the possibility of automated creation of different greening variants for certain circumstances is required. Consequently, through the incorporation of these two innovative features into the greenery for buildings and information modelling for simplification, it is possible to minimize efforts in the planning processes, explore numerous variables, and thus facilitate decision-making for the improvement of sustainable cities [31].

3 Approach and Methods

In order to obtain a holistic view of an optimal BIM model for greenery systems application, we developed a parameter-based classification that could be used to generate vegetation-based models into the BIM authoring software. Various parameters need to be considered during the BIM process so that the simulation can be performed with maximum accuracy. A range of key parameters for greenery systems is defined in this work through the review of existing standardizations. Besides, the information on websites and product datasheets from manufacturers was used in this phase of the study.

Through the analysis of the existing greenery system elements, their features, and challenges from the pre-design to the maintenance phase, we determined parameters that played a significant role in the process of greenery information modelling for achieving an optimum GIM model. Eventually, the selected parameters were classified into eight main groups according to their functions and impact. The focus was on the parameters to be later modelled into REVIT, as REVIT allows parametric modelling through "families." This classification could then be applied to all the BIM authorizing systems. (In REVIT, properties of elements are labelled as "parameters", which are further divided into different categories such as family parameters, system parameters, shared parameters, global parameters, project parameters, etc.)

In the next step, once the identification and classification of the parameters had been completed, research was conducted to know how much BIM technology has been used in the design and construction phases of greenery. To this purpose, we performed an analytical review of the existing literature on BIM integration into greenery systems worldwide. Due to the wide range of approaches, it was necessary to narrow down the scope of our research. In pursuance of regulation on sustainable strategies for BIM application in public and private projects, an increasing number of buildings have been developed in Spain over the past years benefiting from BIM technology. Madrid and its metropolitan area have a Mediterranean climate with hot summers and cold to mild winters, so converting the capital city to a suitable environment for implementing greenery system projects seemed a fair goal.

Ultimately, six vertical greenery systems in the different parts of Madrid were selected. The main criteria for the selection of the case studies were their dimension and type. The greenery systems were chosen considering the quality of design and complexity in construction. Since the application of BIM requires cost, time, and expertise, private buildings of limited size and area offered poor implementation prospects. Therefore, the greenery systems with a surface area lower than 100 m^2 were excluded from this analysis.

Only living wall systems (LWS) were considered, since LWSs can be characterized as self-sufficient vertical greenery systems that are attached to the exterior or interior surfaces of a building. The LWS is a more recent and modern approach in comparison to green roofs and traditional facade greenery systems and needs more complex consideration of design factors, calculations, and equipment for design, installation, and maintenance. The environmental properties of LWSs are remarkable, for this reason, the existing regulations are encouraging architects to use them extensively. In this research, the main focus is on the buildings with exterior greenery systems, since the majority of interior greenery systems are small-scale.

Data were collected from technical information, the website of architectural and construction companies, and existing research papers. Analysis of selected case studies was performed according to the year of implementation so as to compare their specifications to the existing standards and regulations up until the year of the specified LWSs construction.

4 Results

4.1 Results from Parameter Analysis

The representation of greenery systems and BIM application has been limited to certain factors that were potentially apt for modelling and simulation. To be more specific, the geometric subdivisions are adopted in the design phase and the requirements of the plants and systems are taken into account when placing the greening system on the building. To integrate BIM into the greenery systems, it is necessary to develop intelligent BIM objects that are effective not only in the planning phase but also throughout the entire life cycle of the project. Therefore, in addition to the spatial parameters that determine the physical shape of the vegetation objects, other parameters should be embedded into the vegetation BIM objects.

The most regular parameters that should be considered are Type and Classification, which identify the greenery system's general information, and also associate the BIM authoring software with the centralized vegetation library. In order to incorporate a wider range of systems and applications, parameters such as Design Aspects should also be considered. The design aspects include the factors defined in the preliminary stages of the simulation process, and close observation revealed that any change introduced in their attributes could affect the whole system function.

Moreover, variable changes in Plant Parameters turn out to be also relevant. As mentioned before, plants are subject to considerable changes during their life cycle due to their inherent characteristics. Consequently, consideration of factors such as height of the plant and duration of greening in their different phases is important during the simulation and decision-making stages. Other relevant plant specifications like leaf area index and reflectivity should equally be considered in this classification.

The result of our study also shows the importance of including external environmental factors like solar exposure, shadow and wind; furthermore, other parameters such as Irrigation and Care and Maintenance proved to play an important role in decision-making at an early stage. Additionally, including details about biodiversity, effects on the microclimate, edging profiles on building corners and details on substructure, etc. seems to have a positive impact.

Once the simulation process is complete, it is a vital step for the architects to calculate the costs. Hence, the costs are broken down into costs of planning, design, construction, maintenance, etc., thereby they could be later defined as parameters to be modelled into the BIM programmes.

To facilitate handling and application, we classified the key parameters into the following groups according to their function:

1. Type and classification parameters. This includes parameters that contain information about type of greenery system, its components and their dimensions and materials.
2. Facade Design Aspects. It includes influential parameters that need to be considered for planning and design.
3. Irrigation Parameters. Parameters for irrigation system parameters including water pipes, irrigation hoses, their dimension, material and design.
4. Care and maintenance, including parameters for the maintenance phase and its frequency.
5. Plant Parameter, including important vegetation variables.
6. Stress Factors. The external environmental factors that affect the greenery system's functions.
7. Cost information. Cost parameters to be modelled in different phases of the greenery system life cycle.
8. Other Influential Factors. Parameters that could not be classified in any of the previous groups, but equally important for the designers.

Table 1 offers a systematic classification of the parameters described in this section.

This chapter is a part of ongoing research and can only cover the partial development of the classification. By developing the tools used in previous works, it is possible to collect all data available and process them in an integrated way. The more quality data we obtain to illustrate the effects of greenery parameters, the more accurate and reliable the planning will be. Compared to the conventional static planning methods, this is a more dynamic approach. Further design rules for the greenery systems should be considered in the BIM process as well.

Table 1 Properties and parameter classification. Author: Manouchehri. M

Type and classification parameters	Facade Design Aspects	Irrigation Parameters	Care and maintenance	Plant Parameters	Stress Factors	Cost information	Other Influential Factors
Greenery system type	Placement	Moisture percentage	Accessibility	Plant type	Solar exposure	Planning	Light condition (location, direction and shading from surrounding buildings)
Total dimension of greenery system	Orientation	Irrigation systems (water pipes and irrigation hoses)	Construction	Leaf area index	Shadow stressed area	Design	Substrate
Element dimensions	Coverage pattern selection	Irrigation intervals	Maintenance intervals	Plant height	Wind factor	Construction	Effects on microclimate
Climbing aids	Plant choice		Planting intervals	Reflectivity		Care and maintenance	Biodiversity
Vegetation support structure	Selection of greening combinations			Duration of greening		Demolition and disposal	Growing medium thickness
Substrate	Selection of greening area ratio (percentage)					Substructures	Life cycle assessment parameters
Planting	Material choice						Edging profiles on building corners
	Slope angle						

4.2 Results from Greenery Systems Analysis

Table 2 contains information about six vertical greenery systems in Madrid. The table is divided into several sections including general information such as the location of the building, year of establishment, and architect. It also includes information regarding the type of the greenery system and its technical and technological characteristics. The time gap between the development of the oldest one, the Caixa Forum, and the most recent one (Civitatis) is 10 years. Although the greenery systems under study are all living wall systems, they are different in type and design. Results from the analysis of data reveal that there is limited information about BIM in greenery system construction phases and scanty use of BIM tools.

Results at this stage show that the implementation of BIM only exists at a superficial level of 3-D modelling and does not include modelling of the critical influential factors. The corresponding parameters determined for BIM stimulation in Table 1 have not been defined by BIM tools for any of the six buildings under analysis.

Figures 1 and 4, respectively, show the Caixa Forum and the Midori building green walls that according to our study, lack BIM in their design. Figures 2, 3, 5, and 6 are the photos taken from the same walls indicating the problems in their function and maintenance. Figures 2 and 3 show the damage done to the Caixa Forum living wall plants due to the insufficient irrigation and drainage system situation. As can be seen in Figs. 4 and 5, plants in the Midori building have dried out in some parts. They also show an environment for the growth of algae and fungi has been provided. Aside from affecting the appearance of the greenery system, these issues can cause health problems and impose extra costs. These challenges can be predicted to a great degree at an early stage and prevented considerably with sufficient parameters design and GIM technology application prior to implementation.

Causes for the apparent lack of BIM utilization in greenery systems can be split into two groups. The first group is associated with global trends and existing limitations in the Spanish AEC sector. More specifically, (1) effects derived from the inconsistency of the BIM standards, (2) lack of BIM competency identification, (3) BIM maturity level, (4) high cost of hardware and maintenance investment, (5) absence of tariff standards, (6) insufficient formal training and shortage of BIM experts, (7) lack of interactivity, and interoperability problems between the various applications, (8) shortage of analytical information and last but not least, (9) uncertainty of return of investment and potential savings in new technology [6, 15].

The second group is concerned with the barriers that hinder the development and adoption of BIM in greenery. The main reasons for this limited use lie in the existing challenges for modelling plant components. These challenges include (10) the variety of leaf types, (11) changing properties and parameters of plants due to complex biological features, (12) lack of information from producer companies.

Table 2 Specifications of the greenery systems under analysis. Author: Manouchehri. M

Name	Location	Year of Establishment	Type of greenery system	Area	Architect	Use of BIM	Other facilities
Caixa Forum	Paseo del Prado 36, Madrid, Spain	2008	Hydroponic system	460 m^2, more than 15,000 plants, 24 m height	Patrick Blanc	No	Polyurethane sheet is anchored to wall of building leaving a gap that allows passage through its interior for monitoring, automated irrigation and fertilization system
Crystal Tower	Paseo de la Castellana, 295 C, Madrid, Spain	2009	Continues Living Wall/ Indirect	250 m height, 600 m^2	Cesar Peli-Patrick Blanc-Ortiz León Arquitectos	No	Located in the building with A certification, without soil substrate, plants grow on a felt panel irrigated with nutritive substances through a network of tubes controlled by solenoid valves

(continued)

Table 2 (continued)

Name	Location	Year of Establishment	Type of greenery system	Area	Architect	Use of BIM	Other facilities
Hotel Santo Domingo	Calle de San Bernardo 1, Madrid, Spain	2011	Modular pot system	25 m height, 1026 m^2, more than 110 species the plants	Félix González-Pasquín Agero	No	Uses planter box and soil, the irrigation system utilizes the used water of the 50 rooms, utilizes an advanced illumination system during the night
Midori office building	Calle Antonio González Echarte 1, Madrid, Spain	2012	Continuous living wall	5% of the whole facade that is 175 m^2	GBIG Buildings	No	Use rainwater for plants to save 50% of irrigation water, the building holds LEED gold certificate 2015
Vertical Garden Ayuntamiento de Getafe	Plaza de la Constitución, Getafe, Madrid, Spain	2012	Modular Green facade	110 m^2, 3186 plants	Paisajismo Urbano with collaboration of Urbanarbolism	No	Has an ornamental fountain with a waterfall, was renovated in 2019

(continued)

Table 2 (continued)

Name	Location	Year of Establishment	Type of greenery system	Area	Architect	Use of BIM	Other facilities
Civitatis Building	Calle Montera 32, Madrid, Spain	2018	Continuous Living Wall	200 m^2, more than 8000 plants, 22 different species	Paisajismo Urbano	No	Vertical Garden System patented by the designing company was used, plant selection adapted with Madrid climate

Fig. 1 Caixa Forum living wall system. Photo by: Manouchehri. M

Fig. 2 Rotten plants in Caixa Forum due to the excessive irrigation. Photo by: Manouchehri. M

Fig. 3 Excess of the substrate moisture in the bottom parts of Caixa Forum LWS due to the insufficient drainage system. Photo by: Manouchehri. M

Fig. 4 Midori building green wall. Photo by: Manouchehri. M

Fig. 5 Dried plants in Midori LWS caused by problems in irrigation system. Photo by: Manouchehri. M

5 Conclusions

BIM is an essential tool that guides us towards achieving sustainable goals in the global AEC industry. The various studies conducted on BIM in the past years demonstrate the positive effects derived from its application. BIM provides the possibility of 3-D modelling in the projects and at the same time coordination amongst all the design disciplines. It also makes it possible to detect errors at the very early stages of the project. BIM technology also allows estimating the costs whilst maintaining timelines and goals. The intelligent (smart) buildings based on BIM use information technology during their creation and operation. As a result, a variety of subsystems that generally operate independently are interconnected, so that the system can share information to optimize the overall performance of the building.

Research reveals the existence of a gap in the integration of BIM with greenery systems. Hopefully, this chapter has shown that integrating greenery systems into BIM is possible and that innovative solutions to existing challenges of sustainable cities can be provided through this implementation. Hence, the process of placing greenery systems in accordance with the buildings and urban development needs

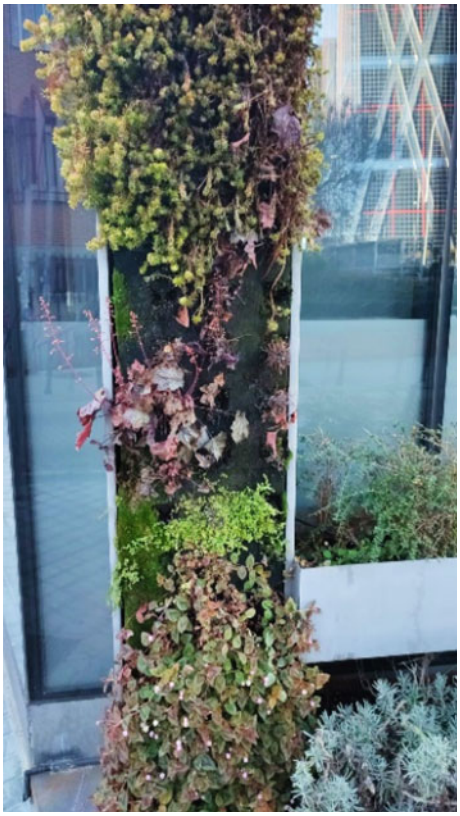

Fig. 6 Growth of algae in Midori LWS due to the poor maintenance. Photo by: Manouchehri. M

can be facilitated through developments based on various criteria of parameter and algorithm definition. This guarantees a simplification of the design and planning process of greenery placement on buildings and ultimately ensures choosing the best solution.

Greenery systems have a positive impact on urban environments. They can improve air quality, as plants capture CO_2 and produce oxygen. They also absorb dust and filter up to 85% of the particles suspended in the air. A vegetation cover protects the facade from the impact of extreme weather. Greeneries regulate the temperature; they can help manage energy costs, dampen urban noise, provide solar protection, help ecological balance, and they can also improve appearance in cities by hiding unattractive building parts. Green systems clearly contribute to well-being in occupants, quoting K.L. Wolf "Desk workers who can see a green environment from their desks experience 23% less time off sick than those that have an entirely urban view. Similarly, these workers also report greater job satisfaction" [32].

The reduction rate in environment temperature and heat flux provided by a greenery system is directly related to the amount of leaf area in the VGS. In order to conduct greenery system simulation studies using BIM, LAI data appear to be a necessary tool. Moreover, a slight difference within a plant growing average thickness can cause drastic variations in terms of energy saving. Hence, it is important to consider these parameters for BIM simulation in large-scale projects.

Greenery systems without well-considered design parameters may not only fail to achieve the expected sustainable values, but they would also involve additional energy and maintenance costs. However, some factors are difficult to model. For example, the moisture level caused by irrigation is related to many other factors, so considering a minimum fixed input value is suggested under these conditions. Research also demonstrates that simplification is imposed in the shape and design of the projects due to software and modelling limitations, which may result in lower accuracy. We have seen how future progress in parameter modelling of greenery systems could solve this problem.

Our study aims to demonstrate that integrating BIM into the greenery system design is still facing many challenges and there are areas for improvement. More particularly, there is a clear lack of BIM objects for greenery systems, which should be supplied by manufacturers and building service connections. This study explores more systematic ways to integrate BIM and greenery systems by detecting influential parameters and classifying them to achieve an optimum model of greenery information. To attain more precise results, building type could be characterized in order to estimate the occupancy level and internal load. Furthermore, building energy performance, local climate area, and impact of living wall in all orientations for different seasons could be included during the simulation process as influential factors.

This chapter proposes an integrative approach for the design of greenery systems, their composition, and their life cycle; a comprehensive approach that involves full-fledged use of BIM technology and widespread adoption of sustainable principles which will hopefully contribute to paving the way towards "our common future".

Glossary

AEC Architectural, Engineering, and Construction
AENOR Spanish Certification Association (Asociación Española de Normalización y Certificación)
AR Augmented Reality
BIM Building Information Modelling
BIV Building Integrated Vegetation
BEM Building Energy Modelling
CBIM Commission BIM
COBIM Common BIM Requirements
EC European Commission
EN European Norm
EU European Union
FFW Flora & Fauna Web
GIM Greenery Information Modelling

HBIM Historic Building Information Modelling
IFC International Foundation Class
ISO International Organization for Standardization
LAI Leaf Area Index
LWS living wall system
NBS National Building Specification
NParks National Parks Board
UNE Spanish Association for Standardization
UNEP United Nations Environment Programme
VGS Vertical Greenery System

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