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Review

Sustainable Construction through Resource Planning Systems Incorporation into Building Information Modelling

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Abstract: The latest industrial revolution 4 enabled significant performance improvement through technological advancements. Simultaneously, the industry is setting high-level expectations for changing business practices toward long-term benefits in all three sustainability dimensions. The concept of sustainability embraces all production and operation processes in the Architecture, Engineering, and Construction (AEC) industry. This study systematically explores the literature on sustainability with Enterprise Resource Planning (ERP) and Building Information Modelling (BIM) technologies in the AEC industry and the sustainability vision for their integration. The different types of ERP and BIM implementations have similarities in addressing the broad scope of functionalities. The emergence and proliferation of ERP and BIM have brought crucial changes to the business environment. Further evolution to cloud-based operations is transforming companies from technology-oriented practices to data-centric decision-making smart infrastructures. The narrative literature review investigates the sustainability insights and ideas in ERP and BIM solutions, presenting state of the art on systems integration topics. The relevant literature was retrieved to achieve the research objectives which were qualitatively analyzed to generate the basis for further research.

Keywords: sustainability; BIM; ERP in AEC; integration

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1. Introduction

There is no doubt that sustainability has become one of the most critical challenges. In the construction industry, sustainability issues have been greatly important due to the emerging concerns about the ecological and societal consequences of construction activities [1]. Construction is a project-based industry and has played a key role in shaping modern project management. Adopting sustainability standards for projects is complicated due to its inherent temporary nature, which seems to contradict stable long-term goals of steady, balanced growth [2].

The industrialization of the AEC industry brought significant improvements in construction process automation. The intent is to concentrate efforts on core value-added activities by automating tedious, error-prone tasks. However, innovation implementation is not as smooth in practice and is associated with many challenges in information sharing and systems integration [3].

Research conducted by The Box [4] indicates that the information economy is significantly more shattered in the construction business compared to the manufacturing, software, media, and entertainment industry. Information flow is increasingly based on digital data transmission. It means that, for instance, paper document-based data transmission is decreasing in numerous industries as digital data transmission is a significantly faster and safer way to share information with other people and organizations [5]. This trend is not as strong in the construction industry as in other industries, and site operations are still strongly based on paper documents [6].

Industry players have attempted to use multiple software for sustainability development in addressing the issue. A significant impact might be achieved through ERP (Enterprise Resource Planning) and BIM (Building Information Modelling) systems integration. This integration enables effective knowledge transfer by harmonizing multiple isolated departments' interactions [7]. Many sustainable performance indicators are not measurable [8]. Therefore, understanding ERP and BIM integration's influence on a company's sustainable performance will be beneficial for resolving the issues by incorporating sustainability practices into project inherited temporary structures.

Today, ERP is an essential part of any business unit, and the advantages of its usage are broadly known and accepted. At the same time, the application of BIM systems is incrementally expanding in the construction industry. Therefore, the integration of these systems is widely discussed among practitioners. However, companies are still reluctant to embrace BIM and its integration with ERP platforms despite the alluring perspectives of creating an optimized and profitable workflow.

The predominant reliance of the AEC industry on paper-based work is the most widespread cause of inefficiency [9]. Although BIM has centralized data from design, planning, and scheduling, it is still a fragmented solution that does not connect to the organization's business processes. Today, many leading construction companies have already implemented ERP and BIM platforms. This implementation creates a strong base for system integrations to synchronize inherently fragmented construction activities. Many benefits are envisioned from this integration, including the reduction in costly, tiresome, and error-prone data entry to maintain system consistency.

The most recent and relevant literature reviews conducted on the research topic by Hewavitharana and Perera [10]; Kolarić and Vukomanović, [11] provide insights on opportunities looming by platforms alliance, whilst the current study explores and compares systems benefits, barriers and stages from the implementation standpoint discussed in the literature and develops a comprehensive review of the state of the art of research topic focusing on ERP and BIM integration-related articles from a sustainability perspective.

The objectives of the study are to address the following aspects of the research topic.

1. To explore the ERP system's contribution to sustainability, which includes benefits and challenges of ERP application in the construction industry throughout implementation to operations;
2. To explore the BIM solution's contribution to sustainability, including the benefits and challenges of BIM application throughout the implementation and operations;
3. To examine the sustainability benefits of integrating ERP and BIM systems in the construction industry;
4. To explore existing challenges and the state of the art of the research topic: main causes of new vision, the evolution of the idea, and current trends.

This paper is constructed as follows. Section 2 discusses the methodology employed for research execution. In Section 3, a literature review is provided for an ERP-enabled vision of a future enterprise with real-time data management capabilities. Section 4 details theoretical knowledge of BIM's role in sustainability trends, focusing on sustainable design concepts with expansion to building performance and facility management issues. Section 5 provides insights into existing ERP and BIM solutions integration studies, concluding with the Section 6 results discussion.

2. Methodology

The selection is based on the research questions and the approach applied to explore the research topic. After the review was conducted, multiple approaches were identified to study sustainability considerations enabled by the ERP and BIM platforms. None of them shall be deemed superior to another and shall be applied depending on the case, considering its rationale and limitation. In this research, a narrative literature review approach is employed to critically evaluate the literature extracted against evaluation criteria.

Based on ERP and BIM solutions examples, the methodology is designed to review the literature on technology advances application in the AEC industry within the sustainability concept. The objective is triple since before any software integration discussion, it is reasonable to identify the benefits of their separate application with further speculation on potential integration opportunities. The authors defined three key focus activities to accomplish the task aligned with the goals set: (i) to set up a search strategy to extract a representative subset of papers on ERP and BIM integration using the most common Scopus, Web of Science, and Google Scholar databases. The search involved all three databases due to the revealed dearth of studies on the integration topic; (ii) to synthesize the subset retrieved; and (iii) to conduct qualitative analysis to review the current state of the art, summarizing current and emerging trends in the field.

The literature review was constructed to search for scientific studies on sustainability performance improvement efforts made with (1) ERP, (2) BIM, and (3) to identify similarities, differences, or overlaps of ERP and BIM while exploring sustainability opportunities of their alliance.

To achieve the objectives set within the research scope, the literature review aimed to explore existing studies in the AEC field. Figure 1 presents and outlines the research methodology applied to this study. It includes four consecutive actions followed by a results discussion. The research consists of mixed reviews to obtain an in-depth understanding, reveal gaps and identify future research directions. The following part discusses the work performed.

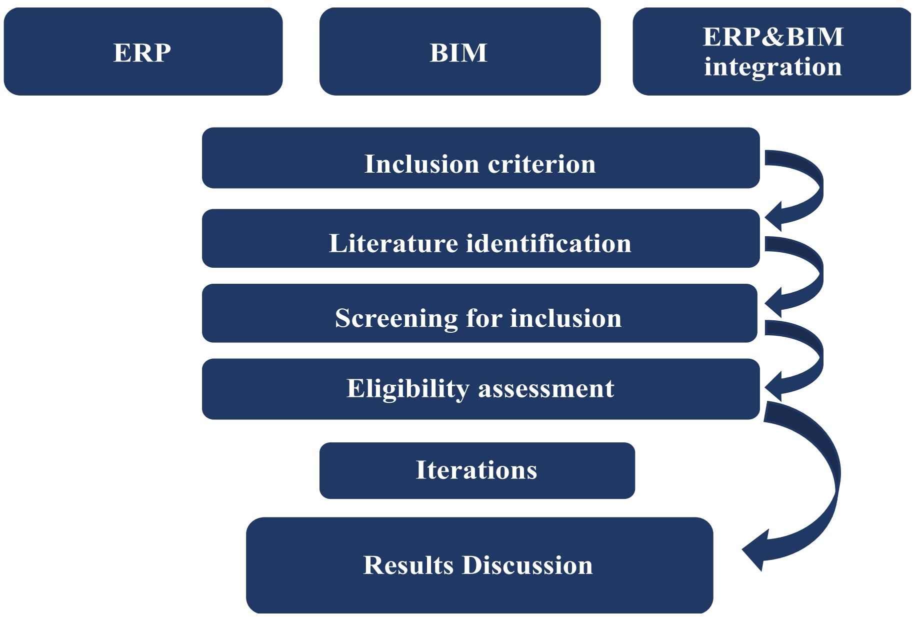

Figure 1. Organization of the methodology.

Inclusion criterion. The literature review covers studies written in English that considered sustainability performance improvement through ERP and BIM implementation in the AEC industry. The keywords identified as: “ERP sustainability”, BIM sustainability”, and “ERP and BIM integration”.

Literature extraction. Keywords have also been searched throughout the text, starting from the title, followed by abstract relevance evaluation. If the content appeared to discuss the role of technologies in the AEC industry-related sustainability issues, articles were extracted for further analysis. No limits were set for the publication period, and papers were examined to discuss ERP and BIM-related sustainability opportunities. Publications were retrieved considering all three research dimensions of research.

Sustainability considerations were searched separately within the articles dedicated to ERP solutions in the construction domain, BIM platforms, and ERP and BIM systems integration. Originally, 113 publications were extracted and analyzed. At the same time, 71 papers are articles from the AEC industry-related journals, such as Automation in Construction; Advanced Engineering Informatics; Journal of Cleaner Production; Computers in Industry; Sustainable Cities and Society; Construction Management and Economics; Buildings; Sustainability, etc. The other 23 publications are proceedings from conferences, such as Creative Construction, Quality of Life, Computing in Civil and Building Engineering, etc.

Screening for inclusion. Abstracts and context screening was conducted to accomplish the screening. No discrepancies were found in the subsets retrieved; all authors agreed on sustainability indicators with the technological advancement in the AEC industry. A total of 97 articles from the initial 116 were selected for further quality evaluation.

Eligibility assessment. Strict requirements were defined for the systems' separate performance. Thus, mostly Q1 journals were considered. Books, technical reports, presentations, and other sources were excluded due to the lack of peer review assessment and validation. In general, the analysis included 97 studies.

Iterations. Due to the scarcity of research works on ERP and BIM integration, the search was conducted forward and backward using different combinations of keywords. Furthermore, references to the retrieved subsets were also analyzed, and 74 journal articles and 23 conference proceedings were included in the full-text analysis.

The analysis generates direction for further research on sustainability opportunities from ERP and BIM Integration.

3. ERP and Sustainable Performance

3.1. Enterprise of the Future

The rapid pace of technological progress brought digital tenets to the vision of the contemporary enterprise. Driven by digitalization and automation, companies are improving their performance, giving technological advances an essential role in their long-term competitive strategy [12]. Hence, the Enterprise of Future centers on intelligence shared knowledge, and business wisdom to be responsive, innovative, and agile in problem-solving and decision-making based on sustainable considerations. Following the current trends in achieving operational excellence, the construction industry is embracing new platforms in a range of applications for design, scheduling, planning control, etc.

In the 1980s, companies used fragmented management systems, looking for a solution that could coordinate all organization's departments on one platform. Further accelerated by the steady growth in data, the need for effective data sharing among internal business units and external partners triggered the development of integrated information systems [12]. This was not an application to support a single business function, but rather a complex system to manage daily operation processes in finance, procurement, inventory, human resources, etc. [13–15]. Further, the internet expansion system evolved from the back office to business intelligence, customer, and Supplier Relationship Management functionalities, covering e-business, e-commerce, e-procurement, e-government, etc. [16]. It also may have contributed to managers' personal development in improving managerial competencies [17].

Therefore, there are no arguments for ERP solution integrity, effectiveness, and efficiency today. Although initially, the main driver was management reports automation [18]. Figure 2 represents the evolution of ERP systems which is a widely acknowledged management solution [9]. It is equipped with up-to-date technologies to meet enterprise technical demands and contribute to corporate competitiveness [19]. It is apt to all organizations' sizes and business needs.

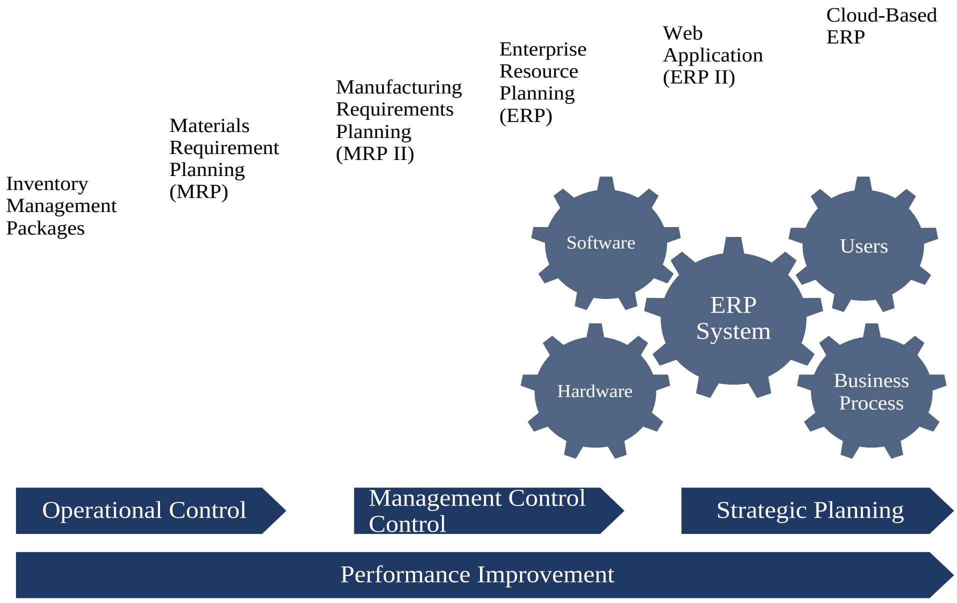

Figure 2. Evolution of ERP Systems.

Many companies have achieved the necessary capabilities to standardize operations [13]. However, initially developed for the manufacturing [20] and production industry, the ERP system, in addition to common complexities, faced several unique construction industry-related challenges provided in Table 1. These are the challenges that result from fragmented [18,21], unstable [12], project-based [15,22], and geographically dispersed industry nature [21,22], leading to the diversity of stakeholders with different levels of expertise and training [22] and resistance to change, with a lack of investment in new technologies [16].

Table 1. Characteristics of the construction industry.

Industry Characteristic	Literature Source
Fragmented	Çınar and Ozorhon [18]; Underwood et al. [21]; Tatari & Skibniewski [23]; Koeleman et al. [24]
Project-based and decentralized activity	Chung et al. [15]; Barreiros et al. [22]; Koeleman et al. [24]
Require specialized systems for specialized segments	Tambovcevs [12]; Sardroud [25]
Unstable and temporary structure	Hasabe & Hinge [20]; Tambovcevs [12]; Sardroud [25]
Geographically dispersed	Çınar and Ozorhon [18]; Underwood et al. [21]; Barreiros et al. [22]
Diversity of stakeholders with different levels of expertise and training	Barreiros et al. [22]
Highly heterogeneous sector	Mexas et al. [26]
Resistance or reluctance to change;	Çınar and Ozorhon [18]
Lack of investment in new technologies and different periods	Mêda et al. [16]
Transient nature of the process	Mêda et al. [16] Koeleman et al. [24]
Lack of replication	Koeleman et al. [24]

There is a multitude of studies on ERP implementation in the AEC industry. Generally, ERP systems research increased from 2000, comprising topics from adoption motivation, followed by benefits and implementation challenges [27]. The research field is further expanded to include success evaluation criteria, factors, and indicators identification. At that point, improvements brought by ERP were not considered through the sustainability facets. When the idea of sustainability was brought to policymakers' attention, the interest in the concept triggered the rapid growth of research on incorporating sustainability into business practices, production, operations, etc. [27]. Emerging trends expanded the system's vision [16] to the Sustainable Enterprise Resource Planning framework. As is depicted in Figure 3, with the operational processes automation, a company gains the opportunity to extend and expand its sustainable programs from the project team to other process stakeholders. Initially, ERP was considered an integrated environment by companies. However, it requires a business process redesign, which leads to changes in workflow. Once the company adopts the system, it reduces paper consumption and turns physical storage spaces into virtual ones. Moreover, this contributes to environmental preservation and addresses confidentiality issues. Improvements in data transparency in its turn help to identify the source of waste, ways for cost optimization and to address several inventory issues, etc. Greater visibility over the entire operation and real-time data facilitates decision-making on operational, tactical, and strategic levels. Thus, sustainability orientation is the driving force in value creation, thinking beyond a profit [28].

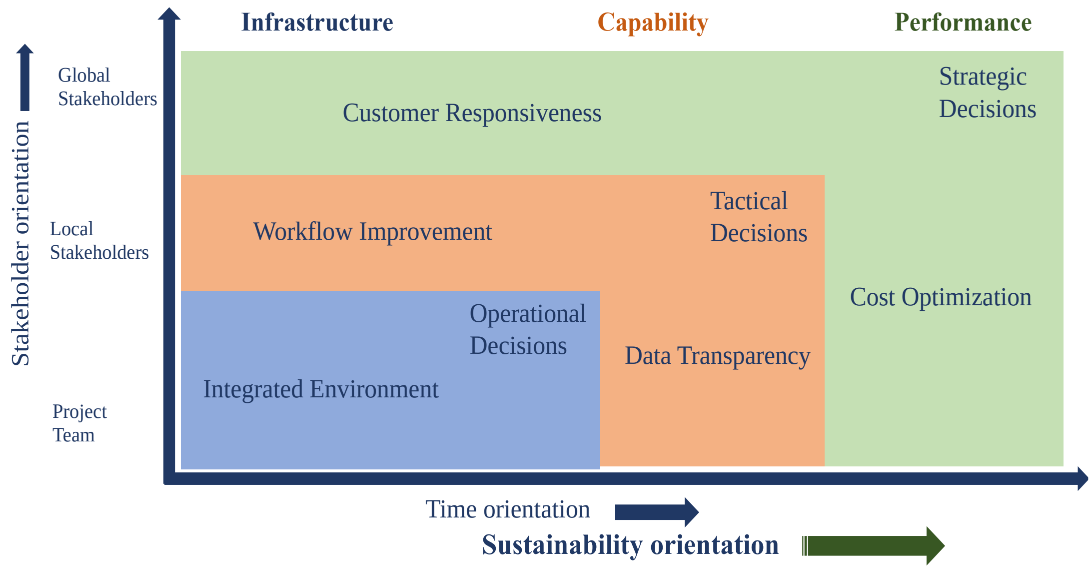

Figure 3. Motivational factors for an ERP system implementation.

The intent behind the initial studies is to reveal the main adoption reasons compared to gains earned and challenges encountered [16]. Interest is raised due to the challenges associated with this implementation and many failed cases [18]. Thus, Voordijk et al. [14] claimed that in the 20th when most Dutch construction companies started replacing nonintegrated information systems with ERP, the initiative produced more failures than successes. The underlying reasons identified were immaturity of the IT infrastructure, cost, and the need for mindset change. Thus, most ERP projects were delivered late and over budget, absorbing numerous unforeseen changes to the original state [13,29].

While Chung et al. [15] highlighted cost, uncertainties, and risks as the main system adoption hindrances, in comparison with manufacturing processes, construction is a project-driven industry. In contrast, owner, team, specification, etc., vary from project to project. Underwood et al. [21] confirm implementation failures due to inconsistencies in standards and issues with data and information level integration maturity. Studies conducted in different countries also mentioned cultural issues [13,29]. The most comprehensive literature review is performed by Hadidi et al. [30], summarizing the major studies on ERP software selection criteria and critical success factors for its implementation. Most findings are based on interviews with ranking criteria and generating importance upon weights assignment.

On the other hand, Cinar and Azorhon [18] searched for key enablers to overcome challenges through various strategies.

To strengthen their market position, software developer companies addressed most of the common issues related to system adoption. Thus, vendors sponsor university programs to train future ERP users, accumulate experience, and improve software [20]. As a solution for temporary construction projects, researchers [20,31] suggested developing additional modules to the existing ERP that can be customized to address variability and uncertainty, expanding the system's intelligence. Naturally, additional time, effort, and investment will be expected from any such kind of customized configuration [12]. It is always better to realign business processes and ERP system offerings since any adjustment requires meticulous attention to detail [32], and is associated with additional expenses. Standard ERP cost components include expenses on (a) maintenance (customization, integration, testing, training), (b) hardware (equipment), and (c) software (modules) [12].

The boundaries of ERP are still under discussion if incorporating project data into ERP is reasonable [16]. Essentially, the object of the system is the enterprise, whereas the project is a temporary activity [16]. Moreover, it is a unique undertaking with exclusive design, resources, and required operational processes, whereas multiple teams work concurrently [32]. However, obtaining up-to-date data decreases as the project's growth becomes detailed and complex, potentially devastating [9]. This effect explains the expectation of immediate impact from ERP implementation, rather than expanding business focus to overall goal and strategy [33]. Therefore, in his study [27], Ali suggested developing an in-house ERP system, claiming that it would not require system customization or readjusting business strategies. Hence, the concept of ERP continues its growth and expansion [20]. While other researchers mostly discussed the implementation challenges associated with large companies, several studies reported similar implementation problems in small to medium-size construction organizations [20,33,34].

In their study, the researchers [14,15,21,29] clearly define the benefits of ERP, such as efficient resource utilization, the development of an integrated solution for the company's business processes by standards, and transparency incorporation. Moreover, Chung et al. [15] state that the major interest of the ERP within the construction industry is in efficiency improvement and, consequently, waste minimization. Analysis of simulation studies performed by Tatari and Skibniewski [23] added improvements in materials management and procurement processes. In this field, ERP contributed largely to reducing paperwork for entering and retrieving data [35]. It is claimed that most of the benefits are in operational and managerial layers rather than a strategic domain. However, ERP has in-built decision support applications, executive data, and analytics to contribute to decision-making [35].

Later in their extensive study, Chung et al. [36] proposed the Success Model, deepening further into identifying key success factors and linking the intention to use ERP with the success of its adoption. Thus the decision on ERP adoption significantly correlates with widely known ERP benefits [36], organization readiness, and commitment [23].

3.2. Real-Time Management Systems

IT enterprise infrastructure comprises technical properties known as real-time data sharing [22], seamless integration, and information processing [23]. According to case studies analyses, Underwood et al. [19] mentioned that ERP solutions play a key role in information centralization. At the same time, a real-time picture facilitates decision-making and addresses routine tasks more efficiently, specifically in terms of project activities, the system controls planning, procurement, production, and logistics subsets [37].

Chofreh et al. [27,38,39] executed several studies on ERP system opportunities, pointing to the importance of accurate and reliable data in pursuing sustainability initiatives. Legacy systems launched green initiatives as separate activities without incorporating them into business processes. An important breakthrough is that the latest innovations shape sustainability, proliferating in all business activities to develop a holistic and complete solution. In other words, this is an integration of sustainability practices, knowledge, and intelligence across the extensive value chain [39].

This integration is very important in globalization, where technology plays an essential role in the concurrent collaboration of all departments and functions across the organization into a single platform [40]. On the other hand, the integration enhances interaction and synchronizes activities with partners. Currently, the company relies on an ERP system for real-time data flow, whether for planning and forecasting related issues or problem-solving.

In the context of the construction materials management module of ERP software, the main focus for evaluation. Obtaining up-to-date information on materials management is critical for project execution. That covers materials management, from ordering the right material to timing delivery [9]. For the production and manufacturing industry, materials management is a core module of ERP that provides real-time visibility on material characteristics and availability, having a crucial impact on operations. However, managing material on a construction site is still full of unanticipated challenges [9]. Any discrepancies lead to disruptions in a construction process, schedule fluctuations, cost overruns, and, therefore, delays in project delivery. The most common challenges include supply delays, outlying materials, incorrect storage locations, stolen materials, schedule shifts, gaps in project planning, manual paperwork, and others. The underlying reasons vary from country to country, from poor materials management systems to a lack of commitment. To overcome these obstacles, the supply chain, being an integral part of ERP, fully employs the latest smart technology to add value with the advancement of the fourth industrial revolution [41]. Therefore, ERP enables the automation and digitalization of the planning, scheduling, ordering, shipment, and storage functions, promoting sustainable supply chain management. Based on ERP data, construction practitioners evaluate performance measures to, in a timely manner, identify risks and develop relevant curbing strategies if required.

Ideally, when a company improves profitability, pursues growth, and creates value for shareholders, its long-term goal will always be sustainable development. In this regard, ERP allows decision-makers to permanently track cash flows, allocate resources properly [19], reveal cost-saving opportunities, and gain a sustainable competitive advantage. It means synchronizing profit increases with social and environmental needs.

Thus, when a company determines the scope of work as a project, all project-related information shall be delineated and separated from daily routine activities. Whereas project management's timely integration into existing business processes creates competitive strategies in the supply chain flow by providing such opportunities as:

- to adapt and respond quickly to dynamic market realities;
- to align planning with vendors and enhance on-time interaction;
- to build robust integrations and create flexibility;
- to improve forecast accuracy and reduce inventory;
- to collaborate on product development.

Different solutions are proposed to incorporate the project portfolio into ERP, such as the integration of ERP with Primavera [9] or web-enabled ERP commerce, including a low-priced way to improve relationships with partners emphasized by Ash and Burn [42]. The most commonly discussed sustainable benefits are provided in Table 2 compared to challenges they can address in technical, social, organizational, and economic dimensions.

Table 2. ERP Benefits vs. Challenges.

Technical Specifications			
Challenges		**Benefits**	
IT infrastructure immaturity	Voordijk et al. [14]	Centralized data storage system	Tambovcevs [12]; Hasabe & Hinge [20]
Inconsistencies of standards	Underwood et al. [21]	Processes standardization	Voordijk et al. [14]; Chung et al. [15]; Underwood et al. [21] Zhang et al. [29]
		Information standardization and synchronization	Chung et al. [15]; Hasabe & Hinge [20]
Data and information level integration immaturity	Underwood et al. [21]	Efficient Data and Knowledge Sharing	Tambovcevs [12]; Hasabe & Hinge [20]
Implementation time	Negahban et al. [33]	Faster response to all functions of construction management.	Anto [35]
Software customization and testing	Tambovcevs [12]	Integrated solutions for the company's business processes	Tambovcevs [12]; Voordijk et al. [14]; Chung et al. [15]; Underwood et al. [21]; Mexas et al. [26]; Zhang et al. [29]; Ali [32]
Social Specifications			
Challenges		**Benefits**	
Cultural issues	Boltena & Gomez [13]; Zhang et al. [29]		
Education and training	Zhang et al. [29]; Negahban et al. [33]	Introduce flexibility	Tambovcevs [12]
Lack of discipline	Zhang et al. [29]	Facilitate cooperation	Patalas-Maliszewska [43]
Resistance to change	Zhang et al. [29]; Hewavitharana et al. [44]		
Mindset change; unwillingness to share information	Voordijk et al. [14]; Ali [32]	Facilitate communication (Applications integration; Internal & external integration)	Tambovcevs [12]; Hasabe & Hinge [20]; van Nieuwenhuyse et al. [31]
User involvement and commitment	Tatari & Skibniewski [23]; Zhang et al. [29]		
Organizational Environment Specifications			
Challenges		**Benefits**	
Risk and Uncertainty	Chung et al. [15]; Ali [32] Negahban et al. [33]	Information availability (real-time), accuracy, and timeliness contribute to the decision-making process	Tambovcevs [12]; Hasabe & Hinge [20]; Tatari & Skibniewski [23]; van Nieuwenhuyse et al. [31];
Organization readiness since it demands critical organizational changes	Tatari & Skibniewski [23]; Ali [32]	Improve management of business processes (More efficient operations allowing for an increase in ability to process transactions (added capacity)	Tambovcevs [12]; Anto [35]
Lack of top management support	Zhang et al. [29]	Time-Saving (Reduction in nonvalue-added activities (lean processing)	Tambovcevs [12]; Hasabe & Hinge [20]; Patil and Attar [34]
Lack of strong and committed leadership	Tambovcevs [12]	Impact on the development of managerial competencies of managers	Mesaros et al. [17]
Vendor Support	Zhang et al. [29]	Reduction in paper documents for entering and retrieving information.	Anto [35]
Focus on immediate impact rather than focusing on overall goal and strategy.	Negahban et al. [33]	Efficiency improvement (shorter intervals between order and payment, lower back-office staff requirements, reduced inventory, and improved customer service)	Tambovcevs [12]; Chung et al. [15]

Table 2. *Cont.*

Organizational Environment Specifications			
Challenges		**Benefits**	
		Materials management improvement	Tatari & Skibniewski [23]; Patil and Attar [34]
		Procurement processes improvement	Tatari & Skibniewski [23]; Patil and Attar [34]
		Errors minimization	Hasabe & Hinge [20]; Tatari & Skibniewski [23];
		Waste minimization	Chung et al. [15]
The conservatism of the ownership group	Negahban et al. [33]	Operations transparency	Voordijk et al. [14]; Chung et al. [15]; Hasabe & Hinge [20]; Underwood et al. [21]; Zhang et al. [29]
Project evaluation (cost, time, involvement); lack of economic planning and justification	Tambovcevs [12]; Negahban et al. [33]	Efficient resource utilization (HR-less transactional, more analytical); Inventory-through better visibility and efficiency	Voordijk et al. [14]; Chung et al. [15]; Underwood et al. [21]; Zhang et al. [29]; Ali [32]
Economic Specifications			
Challenges		**Benefits**	
Cost	Voordijk et al. [14]; Chung et al. [15]; Negahban et al. [33]; Ali [32]	Cost Control and Reduction (Savings through the reduction in duplicated effort)	Tambovcevs [12]; Hasabe & Hinge [20]; Anto [35]
Scarce financial resources	Tambovcevs [12]	Periodical budget tracking is narrowed to real-time tracking, creating chances for identifying project loopholes at the root cause level.	Hasabe & Hinge [20]

4. BIM's Role in the Sustainability Trend

Differing from ERP, the ability of BIM to expand its scope to non-dimensional performance such as sustainability enhancement has been discussed from the very first steps of the emergence of BIM technologies [45,46]. Thus, Lui et al. [47] analyzed the topic of publications on BIM and observed that original research on BIM within the sustainability concept was initiated in 2007. Today, there is a plethora of studies on sustainability advanced by BIM.

Despite the widely discussed benefits BIM brought to the AEC domain, companies are still resistant to embracing these opportunities [48]. In his study, Olawumi et al. [46] derived the 38 barriers to BIM and sustainability implementation in the construction industry discussed in the literature.

- Cost/benefit anticipations [49];
- The necessity to invest in BIM education and training of staff [49];
- Reluctance to change established working practices [46];
- Time required to adjust to new technologies [46];
- Lack of knowledge of BIM work processes [46].

Generally, the list resonates strongly with challenges faced by ERP technologies in the early 2000s, except for the requirement for government support and involvement. Yet, considering the substantial difference BIM delivers to industry and all stakeholders, distinct from ERP, BIM application is promoted by the government in many ways [50]. Implementation policies are fostered in three types: government-driven, industry-driven, and mixed approaches. On the other hand, Yang and Chou [50] allocated responsibilities to key stakeholders in BIM promotional strategy as Initiator–to mandate BIM; Regulator–to issue BIM guidelines; Educator–to popularize BIM courses; Demonstrator–to organize BIM experience sharing platforms; Researcher–to explore BIM field from various perspectives.

4.1. Sustainable Design

Building construction and operation have one of the most detrimental impacts on the environment in all industries [51]. The project is often evaluated at the end of the construction cycle or even during operation. At this point, any improvement to sustainable performance or reducing the footprints of construction activities is costly, time-consuming, and sometimes unfeasible [52]. Therefore, researchers agreed to ensure more sustainable deliverables; sustainability considerations must be incorporated into the decision-making process during preconstruction in the preliminary design cycle [53]. Carvalho et al. dedicated several studies to emphasizing the role of BIM in building sustainability assessment [52–55]. At the same time, validated results demonstrated that BIM modeling reveals opportunities for resource minimization through analyzing model alternatives and consequently improving project performance.

All challenges that might occur during project planning or execution raised the paramount importance of the practice of effective data sharing. BIM offers the construction community a platform for effective collaboration to facilitate the design of any complexity level [48] and develop trust [49]. It provides a one-source central hub for effective data-sharing in all project-related domains, such as cost, schedule, safety, and sustainability [46].

Bryde et al. [49] studied BIM within the project management framework and declared positive benefits in cost and time reduction or control; communication and coordination improvement; quality or control; negative risk reduction; scope and organization improvement. Although BIM requirements alongside high-quality personnel resulted in cost and duration increases in several infrastructure projects, the final estimates were recognized as reasonable to ensure the feasibility of the project delivery in a safe manner. Thus, feasibility analyses require a sufficient period to perform in complex infrastructure projects. Therefore, an adequate design timeline shall be allocated for the planning phase. The sustainable design shall be modeled with utmost accuracy and transparency to address multiple social demands [56].

With all mentioned benefits, BIM is acknowledged as a substantial tool in building key aspects of the construction project delivery. Therefore, the demand for sustainable construction is increasing [57]. Oti et al. [45] also highlight sustainability considerations in recent design criteria besides traditional integrity, constructability, and cost indicators. The sustainable design comprises materials and components alternatives analysis [57] and structural design evaluation [45]. These elements may earn credits in green building certification systems, such as BREAM, LEED, Green Globes, etc. In this regard, Wang et al. [58] suggest that existing green building certification systems may guide the development of a sustainable design. Therefore, additional plug-ins shall be incorporated into BIM to connect design components with potential certification points. In this regard, Akhanova et al. [59] provided comprehensive literature on using BIM for sustainability assessment by integrating green building certification systems into BIM technologies. The study resumed that the model shall be developed on region-specific factors, such as local climate and ecosystem, social, cultural, and economic variety.

Researchers define sustainability improvements with BIM application at the design phase in:

- early design decision with the aim of design optimization [45,60];
- energy modeling, starting from the design phase to post-occupancy evaluation [48,58];
- improving acoustic, water-use, lightning, fire propagation, and other measurements via simulation tools [52,58];
- carbon emission reduction for high-rise buildings considering both embodied and operational carbon [61];
- Environmental Impact Assessment, which is traditionally conducted at the end of the design phase, whereas undesirable changes are undesirable [51,59];
- construction and demolition waste management [52,62];
- improve model assessment reliability and time due to manual, error-prone activities [54].

Traditional design methods are rapidly evolving, encouraged by changes in the social, environmental, and cultural landscape. Despite the usage of the BIM methodology, it should be recognized that any proposed suite of models may not be able to handle all the situations that can arise during an actual construction process, such as region-specific factors [54]. Therefore, some modifications would be inevitable. At this point, effective stakeholder management by creating positive relationships and having frank dialogs would be the clue for risk minimization and performance improvement.

Sustainability enlarges the construction projects to consider such elements as site infrastructure and encourages contaminated site utilization to promote remediation of abandoned places. Strong planning, robust monitoring, and model mandating help evaluate expectations at each milestone and achieve positive results.

BIM addresses problems that usually arise from poor communication, lack of collaboration initiative, and technological organization. It accelerates the design process, improves historical data incorporated into the model, and allows for reduction of the errors that appear from lack of information and knowledge. Therefore, BIM is acknowledged as a valuable tool for facilitating sustainability promotion [62].

Conventional construction technologies are often less feasible in large infrastructure projects. They pose potentially disruptive threats to the environment and are cost prohibitive. Moreover, no fragmented technology can be applied to all construction projects. Different applications are connected to address communication issues more effectively. It is where interoperability problems raise paramount importance. These concerns were the driving force of innovation across the industry is searching for cost-effective and less disruptive alternatives, leading to sustainability considerations.

Sustainable design must embrace the well-known three bottom sustainability pillars; it shall be developed within the industry constraints (Figure 4). While project constraints are clear and tangible, there is still a lack of concordance and consistency in sustainable design evaluation criteria [62].

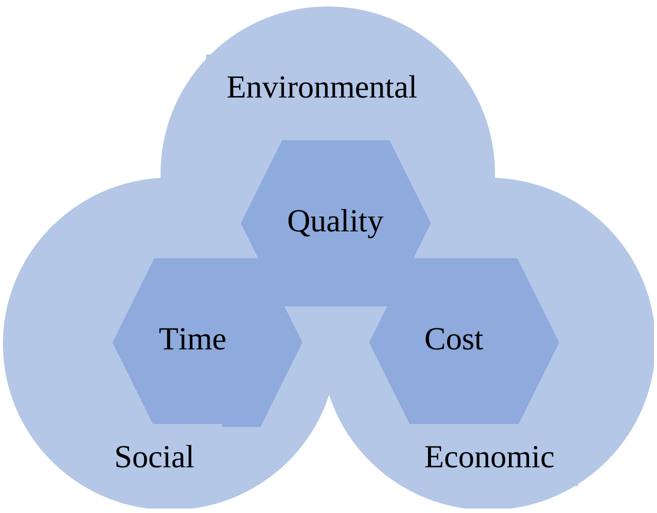

Figure 4. Industry vs. Sustainability Pillars.

4.2. Building Performance and Facility Management

Today, BIM is incrementally advancing to all phases of the construction lifecycle. It is reflected in studies conducted in the BIM sustainability field. In addition to design, construction, and manufacturing [63], the application of BIM in operations and asset management is the next nascent area of BIM research [47]. Al Hattab [64] provided structure rule-based content analysis with the text mining application. They concluded that exploring sustainability under a particular project cycle is one of the directions of studies. Another direction targets BIM functionalities capable of integrating sustainability aspects and stakeholder dimensions.

Generally, the construction industry greatly improves its performance by systematically adopting the innovative methodology. Increasing social demands induce the shift of technological frontiers to respond to stakeholders' expectations. Furthermore, as advanced technologies enable architectures to create more complex designs, the importance of facility management (FM) in asset maintenance is significantly increasing [65].

Initially applied in the design and construction phases, existing BIM tools can tackle existing problems in FM in all three facets of sustainability known as social, environmental, and economical.

1. Environmental Sustainability Considerations in FM

BIM-enabled FM technologies, i.e., computerized maintenance management systems, monitor the effects of decisions made during asset performance lifecycle, allowing for the design modification during project phases [64]. Therefore, the challenges that occurred during the actual construction of the sustainable design can be approached by applying BIM technologies in the asset operation phase. For example, indicators under/overestimating design can be improved by collecting real data [48]. Additionally, there is growing interest in incorporating the Life Cycle Assessment (LCA) methodology that the AEC industry has recently adopted into the BIM platform to measure and improve the environmental performance of operating buildings [66].

Asset maintenance digitalization aims at improving the efficiency of operations. This process comprises diversified strategies for resource conservation by consumption reduction and performance monitoring to better plan the repair and renovation works [47]. In addition, contribute to emergency preparedness and response transition to decommissioning or repurposing life cycles [67].

2 Economic Sustainability Considerations in FM

Researchers explore the opportunities of using BIM technologies in facility management as a knowledge repository to support decision-making [68], management, and planning [67]. In terms of financial performance, the cost of facility operation and maintenance becomes more predictable [68], being the highest expenditure (60%) of the building life cycle [69]. For this purpose, BIM enables requisite data retrieval, analysis, and processing in a digitalized environment [70]. Much longer than the design and construction cycles, the operation and maintenance cycle hides worthy cost-saving opportunities [67].

3 Social Sustainability Considerations in FM

Facility management is associated with a wide spectrum of services required for a facility to operate. Increasing design complexity necessitates more efforts to assure the building fully performs the functions it was originally designed and constructed for. Therefore, effective safety management is designed for risk and hazard prevention. It is where BIM serves as a valuable addition to existing safety standards in procedures, protocols, instructions, and training, as an effective source of requirements for building safe operations. Moreover, BIM-enabled FM systems can facilitate equipment fault detection and diagnosis, whereas visualization capabilities allow for exploring cause-effect patterns [70]. Wetzel and Thabet [65] add that the opportunities of using detailed design drawings, specifications, and models can enhance operation and maintenance performance. Hence, practitioners have yet to explore the potential of BIM in a wider context [49].

Delivering projects accompanied by accurate and reliable data generated throughout the planning, design, and construction cycles is the new vision of BIM technologies brought to the whole asset life cycle. Researchers defined several gaps in expanding BIM for the FM phase [71] in establishing standards for BIM model handover and systems compliance. However, there is also the FM phase-related specifics that hinder BIM-enabled sustainable development enabling BIM.

Data integration to the BIM platform remains the main barrier to developing performance data-driven design [72]. Martinez-Rocamora et al. [73] presented the state-of-the-art BIM and LCA integration, listing different frameworks developed based on linking sources via integration tools or connecting external databases. In contrast, the target is to incorporate real resource consumption data alongside building diagnostics results for further analysis, assessment, and optimization. The inter-operability issues also cover the data exchange from BIM to computerized maintenance management systems. Theoretically, the data format of these systems is compatible, which leads to automate data exchange; however, in reality, it is a tedious process that involves manual work prone to errors [67].

Guillen et al. [69] noted the facility managers' perception of insufficient successful evidence and, therefore, lack of interest from owners. This perception is closely related to the intellectual property rights extensively discussed by Ardani et al. [74], claiming that the BIM model is the product of a multidisciplinary collaboration that generates model ownership problems. It is necessary to clarify ownership rights to decide whether to modify the original BIM model, including real-time operation data, or develop a new model [68].

New model creation is associated with the uncertainty and risk derived from the lack of original construction documentation [69]. It is also true for existing facilities. However, to avoid any data loss, the superfluous or redundant data FM team may reconcile the systematic process of capturing necessary details throughout design and construction cycles, considering further model integration to computerized maintenance management systems [67].

Another issue is the lack of consensus on benchmarks for practitioners as a reference baseline to assess the performance of the design [75]. The topic is scarcely studied. Hence, standards are yet to be established [73].

Although traditionally, FM is perceived as a non-core phase of the construction project, which cannot generate business value and is committed to supportive services [76], it plays an essential role in the holistic vision of sustainable development. The FM cycle is the longest part of asset management that has a significant long-term impact on all three sustainability dimensions.

Therefore, construction practitioners shall yet appreciate the role of the FM cycle and therefore dedicate more efforts to enabling the optimization of FM practices and seamless information flow by providing high-quality BIM models [76].

5. Sustainability via ERP and BIM Integration

The first insights into ERP and BIM solutions integration were presented at the Technology and Automation in Construction-related Conferences. In journal articles, the topic is more discussed in the context of standalone database integration to support data-driven decision-making [77]. The researchers clearly defined the potential of systems integration, such as:

- addressing the internal conflict of existing enterprise processes conflict for better resource planning [78,79];
- alignment of organization procurement processes with project management, hence providing stakeholders with consistent, accurate, and real-time data on project progress [11,80];
- better procurement coordination in ordering the right material and the quantity, raising the awareness of stakeholders about any missing items [81];
- Improve the transparency of site activities, defining the project's boundaries, which allows for a reflection of the financial consequences of any decision [3];
- error-prone activities avoidance that leads to accuracy improvement, labor cost, and focus shift to value-added tasks [82,83];
- cost reduction for onsite activities by incorporating prefabrication and modularization, whereas cost optimization expanded to inventory-associated charges [84];
- streamline sustainability from the design phase (BIM capacity) to business processes in the construction phase (ERP domain) [10];
- provide a more user-friendly and efficient environment for stakeholders [85].

Although several benefits can be envisaged from system integration, the process is still suspended. Possible reasons for delays discussed in the literature are:

- Integration standards shall be developed for the integration of ERP and BIM interrelated databases [11];
- ERP and BIM are conceptually distinct functionality software, whereas ERP is dedicated to the management, not the technical aspect [81];
- Compatibility issues due to different functional structures [10];
- Difficulties with potential savings identification, since besides new system implementation cost, legacy systems integration becomes an obstacle [3].

Santos [85] claims that despite being different, both systems are the product of technological advances to avoid manual, paper-based work. They constitute the integration of modules and are designed to solve the fragmentation of information.

Among other ERP modules, the supply chain and procurement module are recognized as the core artery of any construction project lifecycle, running across planning, construction, operation, and maintenance phases [86]. The project schedule needs to be aligned with the dynamics of the materials supply schedule to reflect risk possibilities for onsite works [87]. With the emergence of ERP systems, the supply chain has undergone fundamental upgrades. However, the main focus of current ERP remains on transactions and operations activities involved in planning and managing the data for decision-making. There are still many areas that need improvements, including the interconnection of cross-functional data on material shipment and delivery schedules. Therefore, some researchers suggest digitalizing the supply chain and procurement to apply to the construction environment [86].

Although a construction team is competent in onsite processes, offsite activities bring risks and uncertainty that are difficult to handle. Therefore, having a full picture from a single source opens great opportunities for the construction manager to look ahead for better planning. In this regard, Zeng et al. [87] suggest linking materials' lead time to the BIM model to identify potential risks associated with delays and to improve time parameters allocated for task completion. The potential of data flow from ERP systems to improve project data expanded to the BIM hub was proposed by Lakade et al. [9]. It is conceptually represented in Figure 5.

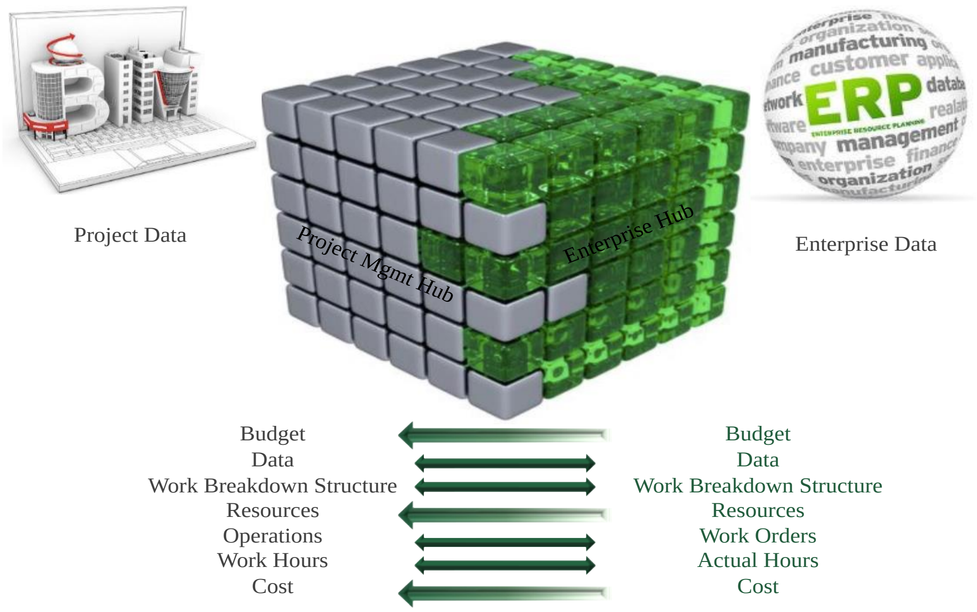

Figure 5. ERP and BIM data exchange.

As we look at the case studies, we see a complex web of objects circulating, communities transforming, and standards emerging, with ERP and BIM at different journey stages. However, these are ordering processes, achieving stable regimes of both boundary and naturalized objects [7]. Dawood and Kassem [88] suggest that the acceptance of BIM by manufacturers may greatly affect the promotion of BIM in the AEC industry. It is noted that although there are numerous studies on the benefits of BIM for construction companies, there is a dearth of studies on the effects of BIM on the manufacturing organization. However, the holistic approach covers data-sharing and workflow improvement from project managers to materials producers through the supply chain.

Holzer [80] adds that many companies in the AEC industry are small or medium size. Despite the looming opportunities, BIM implementation requires impressive investments; therefore, embracing new technologies is undesirable at this point. This reluctance to adopt BIM is compared to that of ERP in the 1990s by Santos [85], whereas the most relevant solution suggested is marketing promotion. Furthermore, Wu et al. [77] highlight that besides fragmentation and heterogeneity of data, other existing construction systems integration barriers are underexplored. Holzer [80] states that establishing protocols for interoperability is another challenge that need to be addressed for an efficient data-sharing establishment. Shirowzhan et al. [89] support that interoperability has always been a challenge in any software integration. However, the full potential of BIM realization cannot be without systems integration and its transition from the design stage to the construction itself.

Automated data derivation directly from object-oriented ERP and BIM has recently been introduced by Autodesk [80,83]. For example, digitizing the most tedious and error-prone material quantity take-off exercise becomes available to the mainstream construction market. Thus, Barkokebas et al. [83] provided the results of this solution, which significantly reduced the duration of value-added tasks by 22% in the pre-award and the duration of necessary waste tasks by 47% in the post-award.

6. Study Proposal

This section summarizes the findings and observations derived from the research performed. The target is to build a basis for future studies on the digital ecosystem gained by ERP and BIM systems integration.

Despite more than thirty years of development, the sustainability concept remains a complex challenge the world faces in global climate change, exhaustion of resources, and biodiversity loss. All the implications described provide a plethora of opportunities for further research. The most urgent need is to reconsider construction activities for being most detrimental to habitat, hazardous and accident-prone working environment, and have opportunities for cost-saving. More importantly, these additional restrictions force industry to innovate in re-evaluating all available technologies, business processes, and even materials selection and footprint analysis.

Sustainability practices implementation also benefits from prior data exploration and post-decision evaluation of outcomes on dimensions of sustainability. Evaluating, comparing, and analyzing the existing and emerging methods of business execution for sustainable performance is not only voluntarily driven by researchers in the field but also mandated by industry and state authorities of rising global concerns.

Hence, accumulated knowledge in the field allows us to evaluate construction performance in the context of sustainability and provides insights into where sustainability practices can be further incorporated to improve the relevant indicators. A trade-off exists between the cost of the project and its feasibility in satisfying the needs of society. At the same time, technological advances are expected to improve the value of local ecological situations and wildfire protection. The researchers agreed that the green considerations should be prioritized at each project execution phase with a major focus on the planning stage. Both platforms were initially intended to integrate business management processes [85] and information management of the construction lifecycle functionalities [90], focusing on the planning aspect [31,69]. However, later on, they expanded beyond the initial boundaries towards substantively enhancing decision support capabilities [31] and creating smart, sustainable environments [90]. In the long term, such improvements in decision-making facilitate achieving more sustainable outcomes [19].

This literature review shows that sustainability in a construction project has been notably studied and discussed by the academic community [2]. However, the role of

ERP and BIM integration in the sustainable improvement of a construction project is underestimated. The intersection theory of sustainability in construction is yet to mature in terms of conceptual structure and the corresponding compounds [91]. High-complexity technologies are more exposed to implementation failure. Frustrations were reported in a range of industries. However, the situation in the AEC domain was aggravated by its heterogeneity [26].

Most of the studies retrieved employ questionnaire-based surveys and case studies with interviews. These two different methodologies are primarily exploited in engineering research [18]. The methods employed are supplementary, as, according to researchers, questionnaire-based surveys prioritize major elements related to research questions to focus on, while case studies with interviews, on the other hand, target answering the "how" and "why" problem or phenomena occurred, providing a more in-depth analysis [18].

Different results were obtained from research efforts to comply with all three objectives. Firstly, sustainability considerations advanced by ERP within the AEC industry are scarcely discussed in the scientific literature. The underlying reason might be the concurrent emergence period of the sustainability concept developed in a parallel timeframe with the ERP solution. Moreover, construction remains the industry that is the least reluctant to embrace ERP. This resistance is explained by field-associated challenges, known as fragmented and project-based nature, etc. Second, opposite results are achieved in BIM-enabled sustainability-related research. There are a plethora of studies discussing BIM brought improvements to sustainable development. Improvements are explored within all three aspects, namely, social, economic, and environmental concerns. Finally, a limited effort is observed in studying ERP and BIM systems integration. Most of the articles on platform integration retrieved are conference proceedings with no further development.

Additionally, the literature review shows that the construction industry projects focus mostly on reducing harmful environmental effects of the construction processes and cost aspects out of the triple bottom line [92]. At the same time, studies identified that large construction companies are more responsive to environmental protection policies than smaller entities [1]. Most of the studies suggest that benefits identification and formulation of benefits of a sustainable approach are to be analyzed during the project initiation and planning phase when making an investment decision [93]. This issue has been addressed by BIM application development, and multiple case studies confirmed the positive results [51,56,94]. The only challenge that remained was the ubiquitous adoption of technology.

Being a pioneer of a single integrated solution, ERP presents many lessons learned on system implementation useful for other systems [16]. In particular, it is recognized as the driving force of innovation [95]. Differing from ERP, BIM implementation might also be promoted by a governance approach [8], widely exploited when the minimum requirement for any company to collaborate on infrastructure projects is BIM level [56]. Additionally, for large construction companies, any improvement in operational processes and reducing exposure to reputational damage could lead to a competitive advantage [1]. Therefore, a pivotal role in setting the tone of the project delivery process belongs to senior management [96]. Scholars also denote the prominence of government in construction, distinct from other industries, where it has a dual role of the large construction projects owner and policymaker [91]. However, sustainable considerations envision projects to create benefits for a broader set of stakeholders. The important underlying assumptions of this approach are stability in a project environment [96] and compliance with environmental standards at regional and international dimensions [1]. Both systems' contribution to sustainable development is abundantly discussed in the literature, especially in terms of real-time data sharing, enhancing collaboration abilities, and, therefore, better decision-making [43]. Obtaining the right data from a single source platform with additional business analytics applications significantly improves integral efficiency and, therefore, sustainable performance [97].

In ERP and BIM integration, a more extensive study would be required to model interoperable and intelligence-based enterprises. Lack of interoperability with other software limits the software's full potential in addressing sustainability issues [89].

It is necessary to improve data exchange between ERP and BIM [37] and other construction applications, such as those exploited for FM. Among the issues reported was BIM incompatibility with environmental modeling programs, when the building components or material properties might be lost during the transition to simulation tools [61]. Moreover, the export of design data to various simulation tools works only in one direction, which requires manual configurations for the BIM model if the simulation results have to be integrated into the model [64]. Van Eldik et al. [51] add that the inability of BIM to integrate bi-directionally with other software design updates from the Environment Impact Assessment (EIA) application is still manual.

The lack of knowledge in this field currently imposes additional challenges to the methodology of sustainability assessment [43]. To ensure technological advances contribute to sustainable development, it is required to:

- establish strong collaboration between developers and the industrial sector for expanding from research premises to commercialization;
- develop comprehensive guidance mandating the use of sustainable innovation practices.

Among the new trends in the construction field that attract significant research attention is offsite construction [98]. It is a new and innovative vision for construction methods with a high potential for sustainability performance improvement that requires strong cooperation of the construction team with other process stakeholders [99]. Automation of offsite construction processes demands greater data accuracy and the capability to retrieve operational-level knowledge. These trends set additional expectations for BIM and ERP integration.

7. Conclusions

The research project will benefit construction companies in terms of sustainable development. Since governments mandated BIM implementation in construction projects, integrating BIM with existing ERP systems at this point might be a driving force behind long-term sustainable goals. In addition to streamlining the construction project lifecycle, ERP and BIM integration could contribute to creating a vision for industry change.

The existing discussion on the trade-offs between economic gains and environmental sustainability among the scientific community tends to scale toward the latter. According to known as "The Porter Hypothesis," well-structured ecological restrictions do not consider any further implications for companies [1]. On the contrary, new requirements necessitate and drive innovations in operational processes and performance improvements. It leads to a new project framework establishment driven by sustainable principles [100,101]. The developer adds value to software accessibility and flexibility in addressing customer needs, making it more specific and allowing for customized configurations [102].

Scientific publications related to the research topic were retrieved to achieve the research objective by applying the traditional literature review methodology. A sample of 97 articles and conference proceedings based on case studies, reviews, and surveys was analyzed. This covers informative papers, proposals of innovative solutions, frameworks, and techniques. Analysis revealed a link between sustainability and ERP and BIM technologies and their application in the construction industry. Most studies discuss sustainability practices enabled by ERP and BIM technologies separately. The dearth of studies is on platform integration. Researchers may not see the potential of this integration since some developers propose new agile and low-cost solutions for fragmented business processes in the form of common cloud-based platforms. The feasibility of this concept is yet to be discovered.

Despite the contributions of this research, this study still has a few limitations. One of these limitations is the sample of literature extracted, which can be expanded further to explore more studies conducted in the research topic field. The authors acknowledge that despite the extensive use of keyword combinations, some topic-related research could be overlooked. In this regard, a longitudinal study will facilitate the identification of a causal link between technology and sustainability outcomes. However, the results achieved adequately represent the current trends in incorporating sustainability via technology.

Secondly, the study reviews the state of the art of the research topic without detailing the technical aspects of software integration. Undoubtedly technically competent organizations can easily adopt new multifold platforms and nurture a new working environment. At the same time, it is a great challenge for those companies that are not as technically equipped. Long-term motivation will prevail, embracing innovations and building a new environment rather than outsourcing functions, especially when innovative solutions are developed for core-competence activities. During the review, theoretical knowledge was captured from publications, and it would be worth obtaining data from the industry to undertake a comparative analysis.

Furthermore, it would also be valuable to ascertain the opinions of platform developers. The reluctance of developers to collaborate led to the abundance of fragmented solutions on market. Yet, advanced technologies addressed most of the problems in the construction industry, it is time to move towards unified integration to answer the fragmented AEC industry environment. More research might foster more collaboration among researchers and practitioners in developing the existing body of knowledge on technology-enabled sustainability practices. Therefore, further theoretical research and empirical data collection will obtain more robust results. Specifically, the focus might be narrowed to investigating ERP and BIM integration to address existing supply chain issues.

In conclusion, the ERP and BIM alliance has the potential to improve the sustainability performance of the construction industry and develop a single working platform. This research can promote interest in developing a holistic vision and serve as the starting point for further research.

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