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A review of the current and future developments of artificial intelligence in the management and building sectors

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Abstract The integration of Artificial Intelligence (AI) into the management and building sector has witnessed significant advancements in recent years. Traditional methods can fall short in meeting these demands, prompting the exploration of AI solutions. This review aims to identify existing gaps, assess the efficacy of current AI applications and provide insights into potential areas for further development. A comprehensive literature review was conducted, encompassing peer-reviewed articles, industry reports and case studies. The analysis focused on AI applications such as machine learning, robotics and data analytics in the context of project management, resource optimization along with sustainable building practices. The review identifies key AI applications in project planning, risk management and construction processes, demonstrating their potential to streamline operations and improve decision-making. The analysis reveals successful implementations of AI-driven technologies, highlighting their impact on cost reduction, time efficiency and sustainability practices. Additionally, emerging trends such as generative design and smart buildings indicate promising directions for future development. The integration of Artificial Intelligence in the management and building sector demonstrates substantial benefits in efficiency, cost reduction and sustainability, while ongoing research as well as adaptation to emerging technologies is crucial for sustained progress.

Keywords: Artificial Intelligent (AI), Building Sector and Management (BSM), critical review

1. Introduction

Artificial intelligence is the study of concepts that allow computers to perform tasks that appear intelligent to humans. Improving computer utility and comprehending the fundamentals that underlie intelligence are the main objectives of artificial intelligence (Szolovits 2019). Currently, AI is considered the most important and troublesome new technology for large corporations (Benbya et al 2020). AI, together with steam engines, scientific and mass production and digital technology, was considered part of the Industrial 4.0 Revolution (Leite et al 2021). In the building sector, AI was predicted to transform various business models, such as finance, logistics, workflow automation and customer relationship management (Hatami et al 2019). Considering its success in other industries, AI has many potential applications in the building industry. AI can support process automation, project management, safety measures and resource allocation (Schia 2019). By introducing the newest technology to the construction sector, AI can improve the quality of a project while remaining within the project budget, schedule and project parameters (Alavipour and Arditi 2019). Although using AI has many benefits, the building sector has seen that AI is not being used in the region (Mohamed and Mohamad 2021) (Abioye et al 2021). The body of research on AI solutions for smart building applications (Panchalingam and Chan 2021) encompasses the core domains of AI, including machine learning, machine vision, fuzzy logic, expert systems, natural language processing and genetic algorithms. To reduce the obstacles to AI adoption and the potential benefits of the technology for the building sector, this study provides information about potential applications of AI to the development of smart cities. The selected methodological approach (Regona et al 2022) (Yigitcanlar et al 2020) involves a methodical approach. The outcomes are categorized using the four main pillars of smart city development: the environment, society, economy and government. The paper’s primary goals are to conduct scientometric analysis of academic publications related to the subject, compile a summary of BSMs’ functions and qualities, emphasize the advantages of AI in BSMs, report on a number of cutting-edge research topics involving cutting-edge AI techniques for improving BSMs and pinpoint future research directions for digitalizing BSMs.

2. Analysis Publication

To determine the real-world applications of artificial intelligence in the building industry, a thorough review of the published books was distributed. Database (Abioye et al 2021) searches were performed on the SCOPUS database covering the period from 1960 to 2020 (six decades), and data from different databases, such as the Association for Computing Machinery (ACM), the Institute of Electrical and Electronics Engineers (IEEE) and Science Direct, were used to confirm the findings. Meanwhile, artificial intelligence (AI) has been around for decades, dating back to the 1950s, and the choice of these dates was driven by the need to evaluate research opportunities, gaps and issues as well as to understand the trends in the industry's decades-long application of AI in the building sector. A considerable number of very important studies, especially in the domains of computer science, engineering and building, can be found in the Science Direct, IEEE, ACM and Scopus databases, which were chosen for the identification of data. As a result, the primary data source selected was SCOPUS, with complete article downloads and data validation from other sources. It is essential to narrow our search to certain AI techniques because the majority of studies have concentrated on employing these techniques to achieve their stated goals.

The following free text search terms based on the subfields and building sector were used in the search: Model-based Clustering (MBC), Robotics OR Deep Learning (DL), NLP ORAIOR Convolutional Neural Network (CNN), OR K-Means Clustering (KMC) OR Stacked Auto encoders (SAE), OR Recurrent Neural Network (RNN) OR Deep Neural Network, etc. This was a restricted search for texts written in English. As conference journals are part of a well-known domain that is utilized in building, they were excluded from term searches that yielded more than one hundred articles (Chiu et al 2022). Most conference journals are published as journal articles. Of the 1800 publications that were evaluated, 1272 were deemed pertinent and included for additional analysis. The primary requirements for admission were an assessment or explanation of a topic in artificial intelligence and techniques with practical applications in the construction industry. This approach proved particularly beneficial for the domains of optimization and knowledge-based systems, yielding more than 500 papers each through search results. Table 1 lists certain studies on methods used in the number of publications on the building sector and management. The methodology was subsequently used for subfields with additional categories containing relevant data, such as optimization, knowledge-based systems and machine learning. Figure 1 represents the number of publications on AI applications in BSM from 1960–2020.

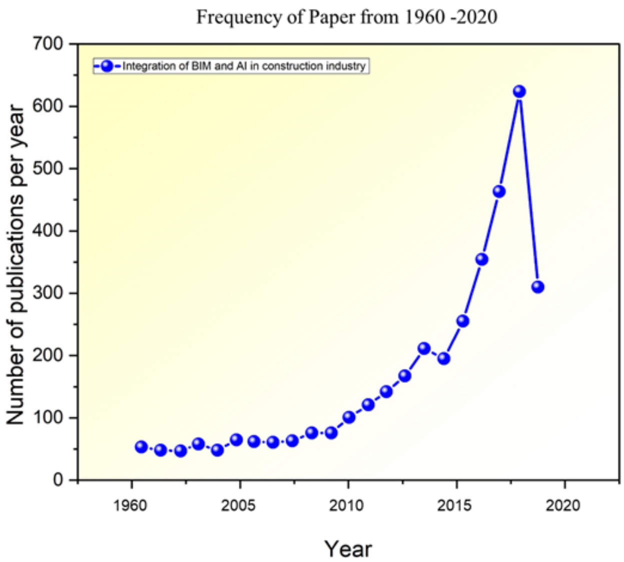

Figure 1 Number of publications on AI applications in BSM from 1960–2020.

3. AI research areas in BSM

The general term AI refers to the modeling of intelligent behavior by computers with little to no human interaction (Kaul et al 2020). AI systems are computer programs that allow machines to behave in ways that resemble human intelligence (Briganti and Le Moine 2020). Traditionally, AI has been used to describe AI, which is human-like and capable of learning, reasoning, planning, perceiving and processing natural language (Patil 2019). A number of artificial intelligence (AI) techniques have been created to enable machines to learn, reason and self-correct, similar to human people. Some of them are explained below.

3.1. Machine Learning

Machine learning algorithms utilize data to create mathematical models, which can be utilized to aid in decision making and prediction. These algorithms do not have specific instructions on how to address problems in their programming. Rather, they 'learn' or improve automatically through experience. The computers can make generalizations from example data with very little help from humans. Machine learning is rather useful when working with large datasets (such as most imaging types, MEG and EEG). It is an excellent fit for professionals who require repetitive routine action because, in some situations, it can perform faster and more accurately than a human translator (Auger et al 2020).

Table 1 Methods used in the building sectors.

Method	Purpose	Number of Publications (Building Sector)	Number of Publications (Management)
Model based Clustering (MBC)	Cluster analysis for pattern recognition in building applications	150	50
Robotics OR Deep Learning (DL)	Integration of robotics and deep learning in building processes	200	80
NLP OR AI OR CNN	Natural Language Processing (NLP) and Artificial Intelligence (AI) for building applications, including Convolutional Neural Network (CNN) use	300	120
K-Means Clustering (KMC) OR Stacked Auto encoders (SAE)	Clustering and feature extraction for building data	180	70
Recurrent Neural Network (RNN) OR Deep Neural Network	Sequential data analysis and complex pattern recognition in building systems	250	100
AI in Building Management Systems	Optimizing energy usage, predictive maintenance and resource allocation	120	180

3.2. Computer Vision

Computer vision is regarded as a multidisciplinary area that combines image processing, informatics and mathematics and tries to provide methods coupled with algorithms for computers to process, decipher and comprehend visual data such as images along with video. Table 2 represents the methods used in computer vision. Computer vision algorithms are used in industry for a wide range of applications, such as automation and inspection (Paraskevoudis et al 2020).

Table 2 Methods used in Computer Vision.

Method	Purpose	References
CNN	Identification of corrosion in structural system	(Chen et al 2020)
R-CNN	Identification of several types of defects in structural pictures, overcoming constraints of visual examination by humans.	(Son et al 2019)
YOLO	To develop a faster, more straightforward single-stage detector for the early and precise identification of numerous concrete bridge defects.	(Zhang et al 2020)
Deep Fully Convolutional Network (FCN)	To create and test an FCN-based fracture identification technique for semantic segmentation on concrete crack photos, with an average precision of approximately 90% and precise crack density assessment	(Dung 2019)
Deep Convolutional Generative Adversarial Network (DCGAN) with Leaf-Bootstrapping (LB)	To increase efficiency in creating artificial images for Civil Engineering applications with DCGAN and LB, as measured by Generalization Ability (GA) and Self-Inception Score (SIS). Putting out a Transfer Learning (TL) pipeline to improve weak classifier performance under low-data conditions.	(Gao et al 2019)

3.3. Natural Language Processing

NLP is a field of research and application that focuses on the practical application of computers' ability to comprehend and modify speech or text in natural language. Table 3 lists certain methods used in NLP. NLP has applications in a wide range of fields, such as machine translation, artificial intelligence, expert systems, multilingual and cross-linguistic information retrieval (CLIR), natural language text processing coupled with summarization, user interfaces, and speech recognition (Chowdhary and Chowdhary 2020).

3.4. Intelligent Optimization

The goal of intelligent optimization is to find the best way to minimize or maximize an objective function while taking a set of constraints into account. Table 4 lists certain study methods used in intelligent optimization. These algorithms are population-based, search for the best solutions and do not require knowledge of the search space. Intelligent optimization algorithms have been used to solve a variety of challenging real-world issues because of their adequate performance and ease of implementation.

Table 3 Methods used in NLP.

Methods	Purpose	References
Unsupervised K-Means-based Clustering with NLP	To assess the efficacy of NLP and unsupervised machine learning for safety inspections	(Cheng 2020)
Systems Theory Analysis	To improve workplace safety, it is important to comprehend the links between the safety risk elements in construction accidents.	(Zhang et al 2019)
Deep learning model	To gain deeper insights from fatality investigation reports using text mining techniques, automatically classify construction accident reasons.	(Zhang 2022)

Table 4 Methods used in intelligent optimization.

Method	Purpose	References
Optimization-based Metaheuristics	To reduce changeover time and increase production output, analytically predict the best product sequencing for off-site construction.	(Deligia 2021)
Hybrid GALP Algorithm (GA and LP)	To create an integrated model with the goal of minimizing overall cost and maximizing profit for time-cost trade-off analysis and finance optimization in construction projects.	(Kouhestani and Nik-Bakht 2020)

3.5. Knowledge-based Systems

Knowledge-based systems (KBSs) are a subfield of artificial intelligence that studies computer decision-making using prior information. KBSs are divided into three categories: intelligent tutoring systems, case-based reasoning (CBR) systems and expert systems (Abioye et al 2021).

3.6. Process Mining

Process mining is a new field of study in the subfield of AI techniques. Table 5 lists certain studies of methods used in process mining. It improves process monitoring along with control by acting as a bridge between operational processes and event logs by obtaining precise and lucid information from actual event logs.

Table 5 Methods used in process mining.

Methods	Purpose	References
BIM application	To enable BIM to record event logs and the digital footprints of project participants during the design-authoring stage of construction projects.	(Pan et al 2020)
Pattern extraction	The popular command sequences for tracking and assessing productivity can be obtained.	(Pan et al 2020)
Social network analysis	Explore social media platforms during the design phase to enhance the chances of cooperation.	(Pan and Zhang 2020)
Analysis of time series	To establish that they can forecast the intelligent design commands that will bring automation and intelligence to the design process.	(Sarker 2022)

4. Building Sector and Management (BSM)

An increasing number of issues that arise and worsen as projects progress limit the ability of the building sector to contribute to the country's economy. Numerous scholars and professionals have conducted conceptual and empirical studies in the field of intelligent systems in various settings to better comprehend and address the intricate issues facing the building sector (Sarker 2022). By examining the most recent and pertinent journals, this paper presents a comprehensive overview of the building sector by summarizing the associated BSM operations and features. Figure 2 represents the uses of AI in BSMs.

4.1. Activities of the BSM

Designing, planning, budgeting and creating something is all part of the finished process of construction engineering. Primary BSM activities can be divided into the following three main phases.

4.1.1. Idea/design and planning

The lifecycle of a building project includes crucial stages for conceptualization, design and planning. Any project must function well to be completed on schedule, within budget and with high quality. Generative design makes design and planning faster, better, and less expensive since it makes it possible to produce the most effective designs depending on any given set of criteria (Schober 2020).

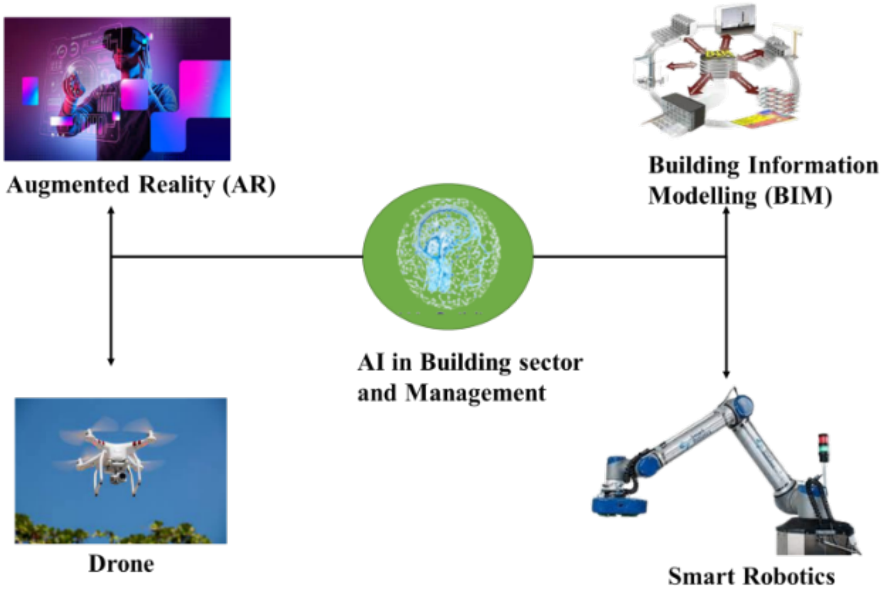

Figure 2 Uses of AI in the BSM.

4.1.2. Construction/Execution

One of the primary causes is the logistical inefficiencies of the construction site itself. First, transfers, reorganizations, idle time and material searches take up nearly thirty percent of the time at building sites. Building projects experience roadblocks caused by delays in the construction process. Ninety percent of large-scale initiatives show some type of planned deviation, are over budget, or are considerably delayed (Schober 2020).

4.1.3. Supply/Facility Maintenance

Facility managers are confronted with a range of choices, including whether to buy new components, challenge an invoice, act right away or wait and replace or repair. Based on the massive amount of information gathered for the duration of the project, facility managers must invest a great deal of time in making these judgments error prone and expensive.

4.2. Characteristics of the BSM

BSM is a technique used to manage a set of related tasks over a predefined period of time under specific constraints, given that construction projects are distinct, transient and progressive in nature for achieving the intended aim. The following five points summarize the main features of BSM, as per the pertinent publications that were retrieved.

4.2.1. Uniqueness

The variances in building projects stemming from client needs, project scale, conditions, impacts and constraints make project management more difficult. Therefore, it is not realistic to simply transfer over a current project's budget, schedule, design scheme and logistics to a new one. Additionally, people with varying functions are arranged in a project, such as providers, builders and supervisors, engineers, designers, and other service suppliers.

4.2.2. Labor-intensive

Building projects require a large amount of manual labor, which can contribute to the physical work required to execute a project and ensure timely and high-quality completion control. The necessity of intense effort in the building process is demonstrated by the expectation that labor charges could account for more than 30% of the project budget.

4.2.3. Dynamics

A project's actual execution cannot follow the plan, even when it has been planned from the start to the finish. Throughout the project, inevitable modifications or adjustments resulting from a variety of factors will occur dynamically. For example, project alternatives can need to be redesigned as a result of unexpected situations and social issues.

4.2.4. Complexity

The task and the participant are the two factors that can contribute to a construction project's complexity. One reason is that construction jobs are complex, multifaceted and interrelated, which can lead to competing schedule or performance issues.

4.2.5. Uncertainty

Uncertainties can be thought of as inevitable hazards that increase the chance of a project failing since they are unknown before they happen. Complicated construction projects are known to have a high degree of intrinsic uncertainty, which is strongly tied to a number of elements.

4.3. Current state of AI in BSM

Construction companies can assess the following early-stage examples: millions of options for project delivery are taken into account by project schedule optimizers, who can improve overall project planning. Future training coupled with education can be prioritized by using image recognition as well as classifications to evaluate video data gathered from work sites and identify risky worker behavior. Enhanced analytics platforms can collect and analyze sensor data to find signals and patterns to deliver real-time solutions, lower costs, prioritize preventative maintenance and prevent unplanned downtime (Ali and Frimpong 2020).

4.4. Future Perspectives of AI in BSM

The three categories of recognized AI systems are drones, augmented reality (AR) and building information modeling (BIM).

4.4.1. Augmented reality (AR)

AR is a system powered by AI that modifies the physical world by superimposing digital data over items and locations. The application of AR technology has become commonplace in a number of sectors, including buildings. AR is used in the building industry for multiple purposes. AR is utilized in presentation and planning. When used in construction, AR can improve the visibility of the specifics and elements from the construction design. Authorities involved in the project can better grasp it by seeing the functional models. Virtual tours can be made with AR technology. This process was conducted prior to the commencement of construction, enabling interested parties to see the project and make any required adjustments in advance.

Related authorities use AR to visually monitor assignment data in real time. This is because AR integrates digital data with papers, simplifying the process for builders, engineers, and architects to monitor and control construction progress without having to visit the site. This keeps all parties informed about the status of the project while saving time and resources (Chan 2023).

4.4.2. Building Information Modeling (BIM)

Among the most sophisticated technologies in the BSM field is BIM. AEC field workers can benefit from advanced improvements in design and visualization, coordination and cooperation, along with construction management, due to BIM technology. The structure, architecture, and mechanical and electrical components of project designs can be modeled in depth in three dimensions using BIM. Construction engineers and architects can help by adopting BIM models to visualize project performance and identify potential issues. By using BIM, construction project stakeholders are more likely to coordinate and collaborate with one another. All parties involved can access the same platform when BIM models are updated in real time for the project (Chan 2023).

4.4.3. Drone

Drones are well-liked AI systems that are in operation and used in the building sector. Drones are equipped with robust systems that can improve construction project performance in a variety of ways. Before and during construction, drones are utilized for site inspections and progress tracking. It can identify possible problems, monitor the status of building projects and identify any site modifications by utilizing drones. A drone's ability to capture real-time photos and videos of a construction site gives engineers, contractors and architects a clear image of the project's progress along with the ability to identify possible problems before they arise. Due to their capacity to collect precise data and measurements on building sites, including elevation, volume and distance, drones are used in mapping and surveying. The operator of the drone must look for ground control points (GCPs) to improve accuracy. If the operator notices any unclear or distorted photographs obtained by the drone, it can be modified using GCPs. This can be done if the drone's height or the camera lens is taking an incorrect image. Drones can ensure the safety and security of a building site by maintaining its condition (Chan 2023).

4.4.4. Smart robotics

Rapid advancements in smart robotics have made it possible to use them in a variety of partially or completely independent building applications. The two main subcategories of robotics are airborne and ground robots. For example, depending on human needs, many construction robot functions have been developed. These robots can perform repetitive operations and automate certain manual processes, including bricklaying, demolition, rebar tying, model creation, prefabrication and other tasks.

4.5. Challenges in the BSM

AI is being used by the building industry later than by the industrial and transportation sectors since AI is in its early conceptual stages of development. The nature of technological challenges varies based on the size, industry, labor and capital intensity, technologies used and business types using the technology of the project. One of the main obstacles to organizations adopting AI is the intricacy of the tasks that analytics perform. The challenges of BSMs are cultural issues, security and information sharing.

4.6. Responsibilities in BSM

In the building sector, there are various ways that AI might help with activities such as surveying, quality control and equipment maintenance:

4.6.1. Measuring

3D models and maps of construction sites can be produced using AI by analyzing photos and data taken by drones and other surveying tools. These models can be used to track developments, identify potential issues, and plan and organize building-related tasks (Mohapatra et al. 2023).

4.6.2. Quality control

AI can be used to track building activities and spot deviations from specifications. AI, for instance, can scan photos of a building site to find flaws in the materials or the craftsmanship, advice management of possible problems before they become serious ones (Mohapatra et al. 2023).

4.6.3. Equipment maintenance

AI can be used to track the effectiveness and upkeep requirements of construction machinery. By analyzing data from sensors and other sources, AI can forecast when equipment will likely break, enabling maintenance staff to proactively fix problems and minimize downtime (Mohapatra et al. 2023).

4.7. Benefits of the BSM

There are various advantages of the BSM. The following lists some of the advantages of AI in BSM.

4.7.1. Automation

With the use of artificial intelligence, project management has become more automated and objective. It is evident that traditional building management relies more on bias coupled with confusion from manual observation and operation and that AI-based solutions help to overcome these obvious shortcomings.

4.7.2. Risk Mitigation

AI has been applied to risk assessment, identification and prioritization. It has the ability to recognize, track, and evaluate any risks in terms of cost, quality, efficiency and safety across teams and work areas even amid extreme uncertainty.

4.7.3. High efficiency

Optimizing difficulties in making building projects run more smoothly and efficiently is another significant application of AI technology. The success of a project depends on expertise, which can direct the process of executing construction more efficiently.

5. Final considerations

The application of AI in the building sector and management fields has been shown to be revolutionary, resolving significant issues and improving a number of facets of the business. The thorough literature analysis carried out for this analysis highlights the noteworthy developments in AI applications, such as robotics, machine learning and data analytics, especially in project management, resource optimization and sustainable building techniques. It has been demonstrated that effective AI-driven technology deployments expedite processes, lower expenses, increase time efficiency and support sustainable practices. The identification of important uses for AI in project planning, risk management and building processes highlights the adaptability and efficiency of technology in fulfilling industry demands. Additionally, research into cutting-edge concepts such as smart buildings and generative architecture indicates exciting new avenues for advancement. Overall, the literature analysis emphasizes the significant advantages of integrating AI in terms of productivity, cost savings and sustainability while emphasizing the continued need for research along with technology adaptation to assure further advancement in the field.

Ethical Considerations

Not Applicable.

Conflict of Interest

The authors declare no conflict of interest.

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