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THE ROLE OF ARTIFICIAL INTELLIGENCE IN ACHIEVING SUSTAINABLE MAINTENANCE IN RESIDENTIAL BUILDING

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ABSTRACT

In light of the emergence of the concept of artificial intelligence (AI) and its various applications, it has become imperative to seek different solutions to address the accumulation of problems and deficiencies in residential buildings and avoid traditional periodic maintenance practices. This research fundamentally discusses the role of AI in achieving sustainable maintenance through its strategies to extend the assumed lifespan of the building and preserve residential real estate assets. This research assumes that the implementation of intelligent exploratory methods offers an effective solution by enabling unsupervised algorithms to efficiently find deviants from a large amount of data. AI is beneficial for both real-time and post-event processing. Where it can be applied to activate large amounts of data and have a chance of making sense of the data, various solutions can be achieved for sustainable maintenance in residential buildings to bridge the gap between the different sustainable maintenance programmes and their actual application, which is the primary objective of the research. The researcher will employ a theoretical framework to elucidate the concepts of sustainable maintenance, the assumed lifespan of a building, and AI applications. Subsequently, an analytical framework was used to analyze various international projects (the case studies) and identify the various strengths resulting. then will conclude by employing an applied framework to facilitate the implementation of smart exploratory methods through the benefits of results and recommendations to achieve sustainable maintenance, prolong the assumed lifespan of the building, and preserve residential real estate assets.

KEYWORDS: Sustainable Maintenance, Life Cycle Assessments, Artificial Intelligence (AI), Machine Learning (ML), Internet of Things-Building Information Modelling (IOT-BIM).

دور الذكاء الاصطناعي في تحقيق الصيانة المستدامة في المباني السكنية

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الملخص

في ظل ظهور مفهوم الذكاء الاصطناعي وتطبيقاته المختلفة، أصبح من الضروري البحث عن حلول مختلفة لمعالجة تراكم المشاكل وأوجه القصور في المباني السكنية وتجنب ممارسات الصيانة الدورية التقليدية، ويناقش هذا البحث بصورة أساسية دور الذكاء الاصطناعي في تحقيق الصيانة المستدامة من خلال استراتيجياتها الرامية إلى زيادة العمر الافتراضي للمبنى والحفاظ على الأصول العقارية السكنية. يفترض البحث أن تنفيذ الأساليب الاستكشافية الذكية يوفر حلاً فعالاً بتمكين الخوارزميات غير

الخاضعة للإشراف من العثور بكفاءة على حلول المشكلات الناتجة عن إدارة كمية كبيرة من البيانات وتجهيزها للاستفادة منها قبل وبعد حدوث المشكلة على حد سواء وإتاحة الفرصة لفهم تلك البيانات للتوصل إلى حلول مختلفة يمكن تطبيقها لتحقيق الصيانة المستدامة في المباني السكنية وذلك لسد الفجوة بين برامج الصيانة المستدامة المختلفة وتطبيقها الفعلي، وهو الهدف الرئيسي للبحث . سوف يقوم الباحث باستخدام المنهج النظري لعرض مفهوم الصيانة المستدامة، وعلاقتها بالعمر الافتراضي للمبني، وكذلك عرض لمفهوم الذكاء الاصطناعي وتطبيقاته المختلفة و يستخدم المنهج التحليلي لتحليل مجموعة من المباني الدولية (الحالات الدراسية) ذات الاستخدام المختلف، والوقوف على نقاط القوة المختلفة وإمكانية الاستعانة ببعض تطبيقات الذكاء الاصطناعي في تلك المباني لتطبيقها في المباني السكنية وذلك لتحقيق الصيانة المستدامة واطالة العمر الافتراضي للمبنى، وبالتالي الحفاظ على المخزون العقاري السكني .

الكلمات المفتاحية : الصيانة المستدامة، تقييمات دورة الحياة، الذكاء الاصطناعي، تعلم الآلة ، (انترنت الأشياء - نمذجة معلومات البناء).

1. INTRODUCTION

The global quantity of major existing building stocks has experienced a rise. As a result, there is a growing focus on the sustainable maintenance of these current building inventories, which has emerged as a prominent issue for governments, legislators, local authorities, groups, and scholars. Undoubtedly, existing structures hold significant importance in the realms of environmental, economic, and social progress and impact. While the concept of building sustainability encompasses the three elements, it is evident that the environment takes precedence. However, to optimize the sustainability of current structures, it is imperative to implement sustainable and efficient strategies that effectively address all three dimensions. By incorporating sustainable and efficient practices across a range of approaches, it is possible to mitigate the adverse effects on the surrounding environment. Through the implementation of intelligent exploratory methods that identify different processing patterns, various solutions can be achieved for sustainable maintenance in residential buildings, prolong the assumed lifespan of the building, and preserve residential real estate assets[1] .

The current study will Analyze case studies (1, 2) with different techniques of artificial intelligence applications applied in some buildings, as well as case studies (1) of certain residential buildings, the study of long-term scenarios for the life expectancy of residential buildings, access to recommendations, to bridge the gap between sustainable maintenance programs and their actual application.

The researcher was able to gather the latest findings of researchers in building maintenance, life expectancy of the building, and artificial intelligence applications, which are presented in **Table 1.**, on which the researcher would build his research study.

Table 1. Literature Review

Most of the previous studies have confirmed that:	Concept
- The maintenance of buildings is becoming more intricate as sustainability demands and complicated systems are on the rise. These procedures involve planning, bidding, implementation, and building selection, involving natural resources, materials, and energy[1].	Sustainable Building maintenance

Most of the previous studies have confirmed that:	Concept
- Neglecting maintenance work in buildings poses a safety and life threat, necessitating its ongoing maintenance to ensure its integrity over its life expectancy[2]. - Maintenance work is crucial for building life expectancy and the internal environment, avoiding major repairs. Architects must identify and achieve architectural maintenance technology capabilities during design, implementation, and operation[3]. - Buildings possess the capacity to diminish energy usage and carbon emissions by implementing sustainable conservation strategies, improving energy efficiency, and reducing operational carbon emissions through environmentally friendly mechanisms[1]. - Prior research has shown deficiencies in building maintenance techniques. However, there is an urgent need for further studies to provide sustainable and efficient alternatives [3] . - Building sustainability entails the management and planning of material and economic resources over their entire life cycle. This includes implementing economically and materially sustainable maintenance practices that take into account the projected service life[4].	
- Studies show that 75–80% of a 50-year-old building's total cost is generated during its operation and maintenance, indicating a significant increase in costs due to ineffective maintenance practices [5]. - Maintenance operations negatively impact the environment and economy, as buildings consume 40% of energy and 30% of CO2 emissions during their life cycle, largely contributing to the construction sector's carbon emissions[6]. - The attention given to maintenance activities leads to an increase in the expected lifespan of the building and improves the indoor environment of the building, thereby eliminating the need for major repairs[3].	life expectancy of the building
- There are many new maintenance technologies, like granlund Manager, eco-Struxure Building Advisor, maintenance management system MMS, maintenance and project management PMP and building information Modelling BIM, It's proven to be effective in managing maintenance, but there's still a lack of application[3]. - BIM enables the creation of a virtual model that can be analyzed and tested before the actual construction takes place. This allows for the evaluation of various scenarios based on the building's performance over its whole lifespan[7]. - Integrating various advanced digitalization techniques, such as the Internet of Things, edge computing, and cloud computing, plays an important role in preserving historic buildings [8]. - Monitoring historic buildings' indoor environment helps identify risks, improve maintenance, and preserve cultural artifacts. However, most proposed systems lack general digitization for smart services using artificial intelligence and machine learning[8]. - AI can help address practical engineering problems like inaccurate monitoring of terminal equipment and low-fault	Application 0f AI in building

Most of the previous studies have confirmed that:	Concept
diagnosis. To create a clean, low-carbon, safe, and efficient energy system, a new generation of smarter power systems and integrated energy systems is needed[9]. - AI, as an augmentation of human comprehension, has the capacity to function as a crucial instrument in utilising previous experiences and merging them with current progressions to achieve an improved future [10]. - As AI techniques becomes more advanced, business automation is growing. Technology has also become a popular phenomenon. Specifically, network operation and maintenance [11].	

2. METHODOLOGY

2.1. Sustainable Maintenance

It involves devising a distinct set of actions to establish a valuable and distinctive position, enabling organizations to effectively accomplish their objectives and outcomes. This is achieved by incorporating current circumstances into an interactive strategy that transforms the conventional approach to strategic planning for building maintenance, employing more sustainable methods[1].

Also Maintenance can be defined as the set of procedures and a series of processes to be carried out with a view to maintaining a building and its life expectancy. Through the modern concept of maintenance, maintenance activities can be linked to the life cycle of the economy, where they are considered a combination of administrative, engineering, and technical work related to the preservation of material assets. Buildings available [3].

2.2. Sustainable maintenance strategy

Strategic methodologies aim to mitigate internal vulnerabilities and external risks, promoting competitiveness and consistency in administrative procedures. Implementing sustainable building maintenance practices faces challenges such as environmental aspects, organizational aspects, human resources aspects, technical aspects, financial aspects, building ageing aspects, and user-related aspects ,are shown in **Fig. 1.**. Environmental issues include climate change, organizational issues involve ineffective structures, human resources difficulties include training, technical issues involve technical innovation capabilities, financial concerns involve budget distribution, and building ageing issues involve neglect, energy consumption, and safety[1].

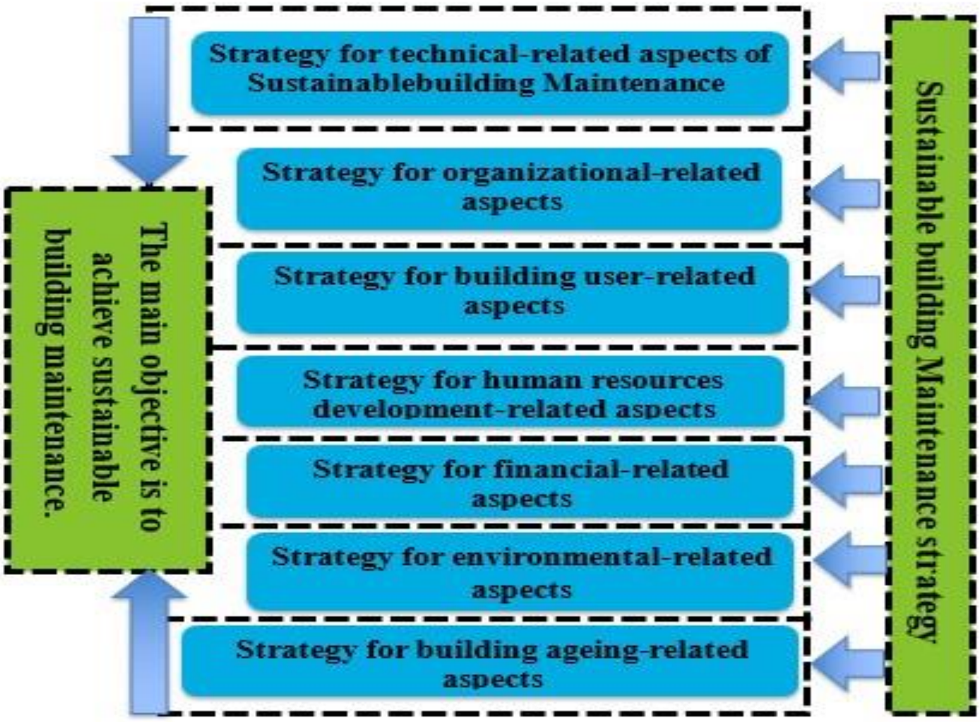


Fig. 1. The main role of Sustainable Maintenance strategys.

2.1.1.Strategy for environmental-related aspects

Building fault inspections using destructive methods cause increased waste, noise, and the risk of accidents. Non-destructive technologies can detect flaws quickly and generate minimal noise, reducing waste. Climate change impacts building maintenance, increasing costs globally. Incorporating climate change considerations into maintenance planning can mitigate risks, enhance sustainability, and reduce risks to structures[1].

2.1.2. Strategy for human resources development-related aspects

Effective building maintenance management requires professionals with sustainability knowledge, industry updates, and active participation in sustainability initiatives. A competent team enhances practices, and ongoing training in maintenance technologies, planning, scheduling, communication, contract administration, and supervision is crucial[1].

On another level, stakeholders should know how to deal with the building and its various parts and attachments in order to achieve the highest performance.

2.1.3. Strategy for financial-related aspects

Building maintenance organizations should adopt a financial development approach to manage budgets, balance income and expenditures, and deliver cost-effective value. This involves long-term planning, a cost-benefit framework, and a well-structured budget. . Optimizing budgetary resources can be achieved through planned maintenance strategies, reduced repair costs, transparent policies, and exploring alternative financial options, such as performing minor tasks internally.

2.1.4. Strategy for building user-related aspects

The establishment of effective user interactions pertaining to energy usage and maintenance is of paramount importance for the purposes of conservation and maintenance. The implementation of effective building management strategies necessitates the elevation of awareness among stakeholders, the provision of comprehensive guidelines, and the systematic collection of user input to enhance overall performance. The complexity and potential hazards of buildings increase when they are not managed appropriately. The integration of developing technology and stakeholder participation is of utmost importance in order to effectively address both present and future requirements [1].

2.1.5. Strategy for organizational-related aspects

Clear job descriptions and responsibilities are essential for directing employees and reducing chaos in maintenance organizations. Proper planning and scheduling of building maintenance work is crucial for reducing accumulation and completing tasks within timeframes. Maintenance plays a crucial role in building sustainability, improving durability, and achieving energy savings. Sustainable maintenance is more convenient, reduces costs, and improves user health and safety. The most effective approach is a sustainable approach for the first decade after building handover[1].

2.1.6. Strategy for building ageing-related aspects

Aged buildings often require additional restoration efforts, such as rehabilitation, to ensure sustainable development and reduce material consumption and waste. This approach is preferred over demolition and rebuilding due to cost, safety, and environmental benefits. Retrofitting strategies can improve energy efficiency and user comfort, particularly in HVAC systems. Mandatory building inspections can address neglect in older buildings, while rehabilitation strategies address structural deficiencies. Eng ageing in the restoration of ageing buildings is more environmentally beneficial than demolition and reconstruction[1].

Assumed Lifespan of a Building and its Assessment Tools

The lifespan of a building is a composite concept where we can find three concepts:

1. Economic life expectancy : It is the time period of a building that is still able to achieve its economic function.

2. Life expectancy : It is the time period of a building that has the ability to deal with the actors and activities involved in the exercise of its function.

3. Technical life expectancy: It is the time period of a building that is estimated on the basis of its main structural type and its persistence and tolerance of different occupancy rates [12].

After the various building life cycle assessment tools appeared, we were able to identify the life cycle expectancy of the building, and with those tools, we were able to prolong the assumed life span of a building by working to scale up those assessments.

Life Cycle Deverse (LCD) Tool

It is a technological tool that is used to assess the occupied parts of the building. This signifies the prevailing construction methodology employed within the approximate timeframe of 2020. Its objective is to examine the potential advantages of extending the preservation of buildings[5] The primary barriers impeding its wider use are the erosion and ageing of building parts due to environmental factors and non-routine maintenance.

Life cycle costing (LCC) tool

It is a widely technological tool to assess a building's economic performance throughout its life cycle. However, its use in the construction sector, particularly in green construction, is insufficient. There are many studies that have found that barriers to its wider application include a limited understanding of its techniques, a lack of standardized guidelines, and a lack of reliable data for its calculations[13].

LCC of the building has proved to be an effective measure in reducing the total cost throughout the building's life[14].

Life cycle assessment (LCA) tool

It is a technological tool to assess the environmental impact of a product, process, or service throughout its life cycle. It quantifies carbon emissions from various activities, including resource extraction, manufacturing, and transportation. it has been used in the construction sector since the 1990s [5].The primary barriers impeding the broader Not to use appropriate environmental treatments in construction owing to the absence of the necessary technical techniques as well as the use of inappropriate materials in the rehabilitation of buildings.

2.1.7.The Significance of Assumed Lifespan in Sustainable Building Maintenance

When we apply the significance tools of LCD-LCC-LCA, we can assess the performance of the building in the short and long term. How ever the occupied parts of the building's economic performance, building environmental impact, which has the most impact on increasing the life expectancy of the building and occupied parts of the building, by working on those assessments to achieve sustainable maintenance by the strategies for building ageing-related aspects and environmental-related aspects.

2.1.8.Strategy for technical-related aspects

Building maintenance is becoming more complex due to advancements in systems. To address this, technical innovation capabilities must be increased, focusing on the control of maintenance work from planning to completion. Designing with accessibility in mind and involving maintenance experts can improve performance, energy efficiency, safety, and cost-effectiveness[1].

Integration of AI applications and BIM technology by IOT can help manage maintenance information, but the application of (IOT- BIM) maintenance operations is still in its early stages, and there is a gap between industry needs, available knowledge, and its application [15].

Artificial Intelligence (AI)

The ability of computer systems or hardware to simulate human intelligence to perform the task, find solutions to problems, and make decisions Without learning or preprogramming the machine, there are many applications of AI [16].

Its applications are related to the field of study, which can help address practical engineering problems like inaccurate monitoring of terminal equipment and low fault diagnosis. To create a clean, low-carbon, safe, and efficient energy system, a new generation of smarter power systems and integrated energy systems is needed, like machine learning[9].

Machine learning(ML)

One of the AI applications that's engaged in creating and folding algorithms that allow systems to learn from gathering information and experience There are three sorts of machine learning:

a- Deep learning

One branch of ML uses artificial neural networks to find algorithms. One of these apps is an artificial neural network.

Artificial Neural Network (ANN)

The algorithms that process the information on the neural abdominal simulator It depends on advance information.

b- Super visor learning

One branch of ML depends on the existence of data building blocks. And it contains two basic types: task classification and linear retreat.

c- Un Super visor learning

One branch of ML depends on training based on structures that do not contain specific speculators or products [16].

2.3. The Role and Potential of Artificial Intelligence (AI) in building Maintenance

Before knowing the real role of AI in achieving sustainable maintenance and through what has been presented, it has become imperative to discuss the role of some technologies, such as Building Information Modelling (BIM) and Internet of Things(IoT), whose integration with industrial intelligence is considered to be one of the most important strategies for achieving sustainable building maintenance, as shown in **Fig. 2.**

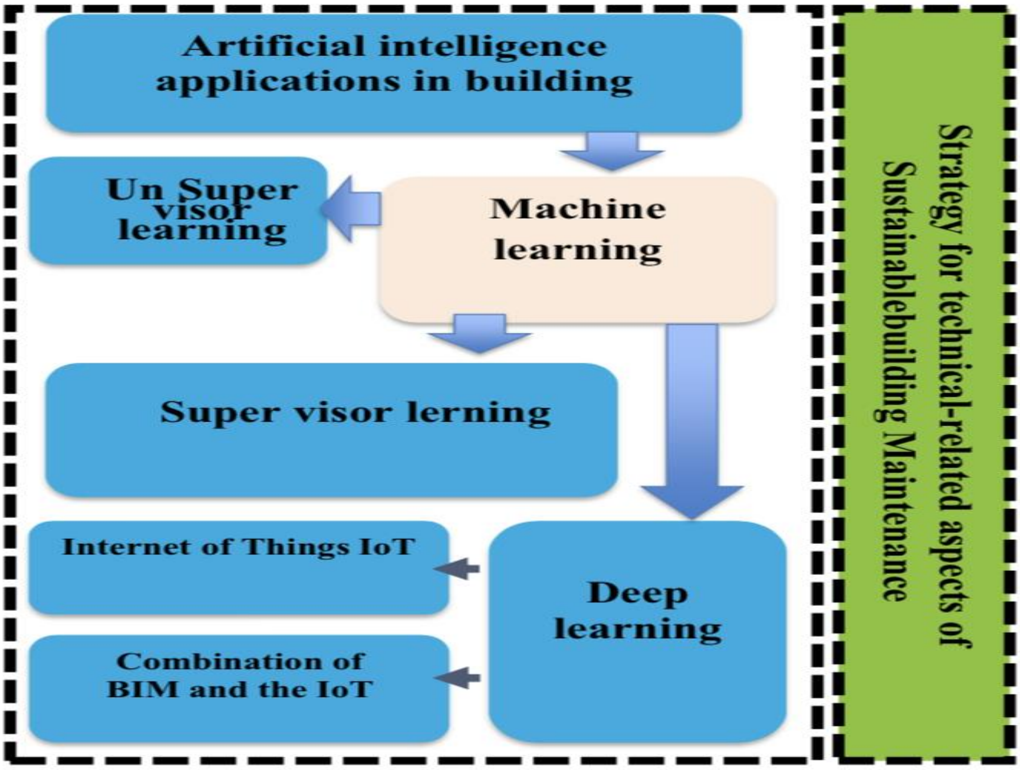


Fig. 2. Integration of AI and IOT-BIM in building sustainable Maintenance.

2.3.1. Is Building Information Modelling (BIM) technology enough

The emergence of BIM technology has led to a global trend in the construction technology industry. The construction sector is witnessing the emergence of information technology as an important model. This technology affects the development of the construction industry. However, the use of such technology in the area of maintenance is still limited to the management of maintenance through the management of available information. There is a significant gap between the existence of information and the reaction resulting from it[15].

2.3.2. Technology of Internet of Things (IoT)

IoT made significant advancements that connected the available information base with response technology to make the possibility of achieving sustainable maintenance possible. It integrates various devices and systems, such as radio frequency identification (RFID) devices, infrared sensors, laser scanning, embedded systems, and other systems, into a huge network system.

It was important to use efficient networking technology to collect BIM information and integrate it with AI applications in order to harmonize digital simulations with real-word building information and apply that information by AI technology. The integration of these two technologies represents the future course for achieving sustainable maintenance and its applicability[15].

2.3.3. The combination of BIM and IoT

The combination of BIM and IoT connects physical infrastructure with information technology, enabling the handling of both fundamental and extensive project data. It digitizes spatial locations and collects operational data using sensors, enabling real-time transmission.

The architecture of IoT- BIM system comprises three layers: perception, network, and application ,as shown in **Fig. 3**. The utilization of this particular design pattern is commonly observed in the field of engineering studies, where the refinement of application scenarios takes place mostly at the application layer. this integration is becoming more prevalent in engineering projects, encompassing the many phases of design, building, and maintenance[15].

Although the IoT faces challenges in accessibility, application, and analysis of data. it generates massive amounts of data, making it difficult to collect, analyze, and process it quickly and effectively. The data generated by big organizations is often chaotic and unformatted, making it difficult to understand. AI offers an effective solution by enabling unsupervised algorithms to efficiently find deviants from a large amount of data[17].

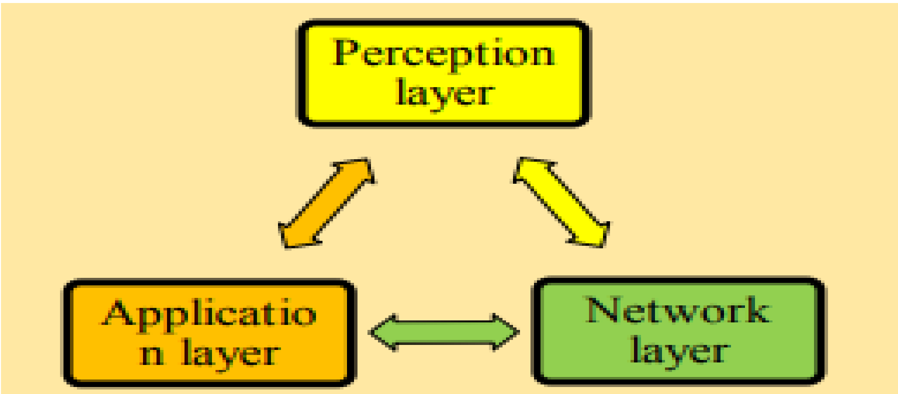


Fig. 3. Basic architecture of the IOT-BIM system[15]

2.3.4. How can AI enhance the Internet of things

There is a clear intersection between the IoT and AI, IoT revolves around the interconnection of machines and the utilization of the data they generate. AI involves the replication of intelligent behavior in many types of technology. Given the immense data generated by IoT devices, the utilization of AI is imperative to effectively manage these substantial quantities and extract meaningful insights. AI is advantageous for both immediate and subsequent data analyzes. Post-event processing entails the identification of patterns within data sets and the application of predictive analytics[15]. So we could take advantage of that relationship for sustainable building maintenance. Where it can be a applied to activate a vast amounts of data and have a chance of making sense of the data to bridge the gap between sustainable maintenance programs and their actual application.

2.3.5. The application of AI frameworks in building maintenance

The digitalization framework comprises three key components, namely perception devices (a), edge platforms (b), and cloud platforms (c), as shown in **Fig. 4.** Perception devices offer valuable data pertaining to buildings, like temperature and relative humidity, CO2, temperature, air quality, and vibration sensors, which can be categorized into three main groups: collectors and sensors, controllers and actuators, and brokers and other systems. The edge platform facilitates the operation of various sets of perception devices and establishes communication with them via both wired and wireless channels. The edge platform comprises four distinct functional modules, namely the

Aggregator, Local Storage, Local Analytics, and Local Gateway. The aggregator module collects data and facilitates its dissemination to other modules, while the local storage module is responsible for storing logs and analytics. The regional gateway facilitates the synchronizationof consolidated data to the cloud-based platform. The cloud platform consists of four distinct modules, namely Cloud Gateway, Cloud Storage, Cloud Analytics, and Applications. Cloud computing and edge computing can be utilized by researchers to develop, implement, and validate applications aimed at the intelligent preservation of structures [8].

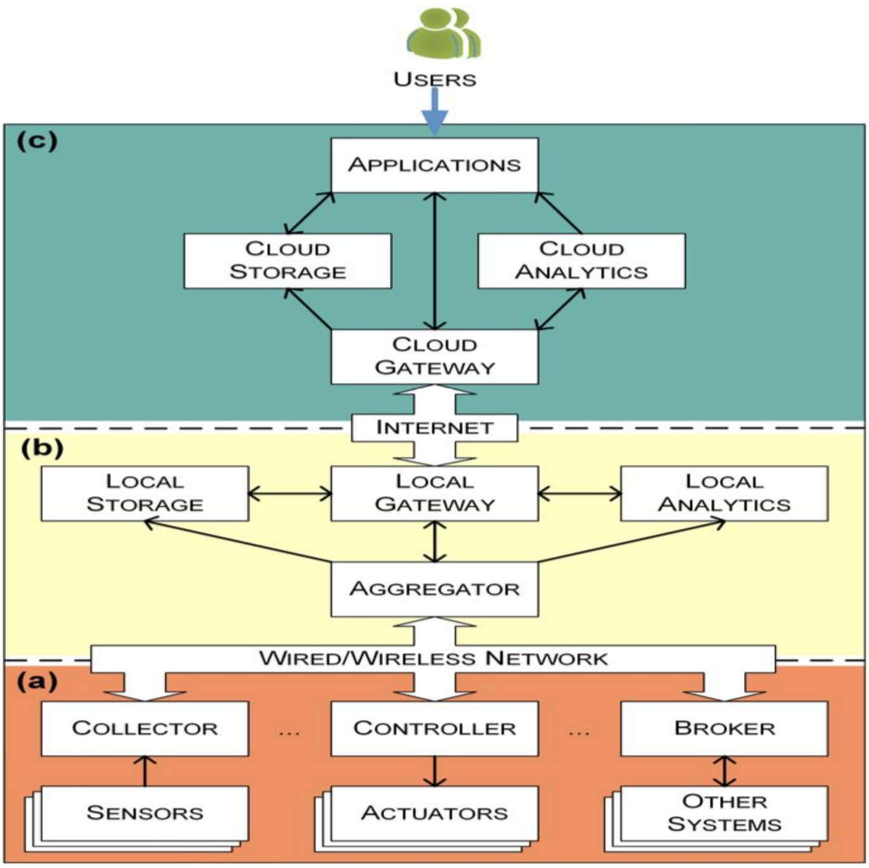


Fig. 4. Architecture of the proposed digitalization AI framework. (a) Perception Devices, (b) Edge Platform, and (c) Cloud Platform[8]

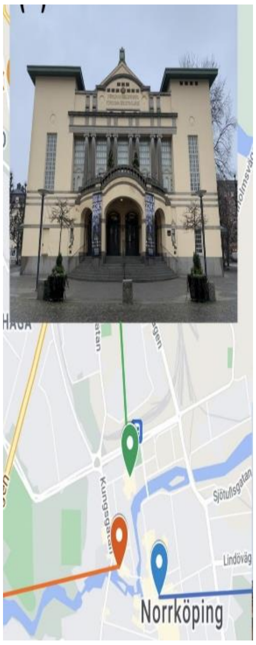
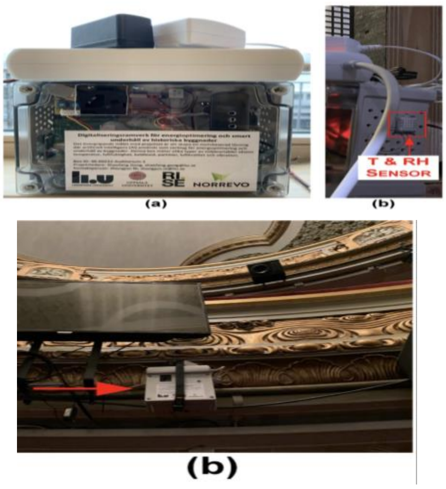
2.4 Case studies

By analyzing a range of international buildings of different uses Case Studies (1, 2), which are presented in **Tables 2** and **3**, through which some application of AI has been applied to reduce environmental impact, sustainable maintenance has been achieved, various strengths have been identified, and some of these applications can be used in residential buildings (Case Study 2), which is presented in **Table 4**, to prolong the life expectancy of residential buildings.

2.4.1. The City Theatre, Case Study (1)

The City Theatre is presented in **Table 2**.

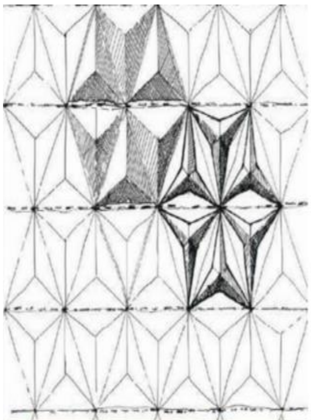
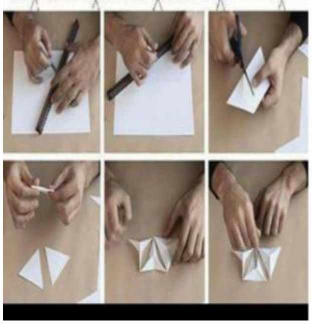
Table 2. Case study (1) Application 0f AI in historical building.

The City Theatre (historic buildings)	Locate : in the city Centre of Norrkoping. Date of establishment: 1908, and it is a representative of the Art Nouveau style. Age of the building: 115 year.	**Data collection and analysis**
	**Design Feature** This study represents a particular system to achieve indoor environmental monitoring and preserve the origins of the building and its historical value. **Application 0f AI** A sensing system is created by combining multiple sophisticated digitalization approaches, including the Internet of Things, edge computing, and cloud computing. The sensing system facilitates remote data gathering, allowing for the observation of both real-time and historical data. Additionally, it enables the performance of real-time analysis, contributing to the sustainable maintenance of historic buildings. Five sensors are used to measure temperatures, carbon, dust, and relative humidity. The sensors are designed to provide accurate and reliable data for building safety[8], as shown in **Fig. 5.**  **Fig. 5.** The assembled sensor box. (a) Front view and (b) right side view[8].	<u>This study emphasizes that:</u> The system uses a sensing system using AI (sensors) and integrates various advanced digitalization techniques, such as the IOT, (IOT-BIM), with a result of: - providing facility managers and users with more applications to control sustainable maintenance in: • internal paints. • carpentry, furniture, floors and vents. • heating and cooling equipment. • water and drainage systems. • Bishops and interior spaces. - Control of internal temperatures, carbon, dust, and relative humidity that damage different parts of the building to achieve indoor environmental monitoring.

2.4.2. Al-Bahr Towers,Case Study (2)

Al-Bahr Towers is presented in **Table 3.**

Table 3. Case Study (2) Application of AI in residential administrative building.

Al-Bahr Towers (A residential administrative building)	Locate: located in the city of Abu Dhabi. Date of establishment: 2012. Age of building: 12 years.	**Data collection and analysis**
   	**Design Feature** This study provides a dynamic building envelope known as a responsive facade. that optimizes a building's functionality by adapting to fluctuations in its immediate surroundings. The design concept of this exterior is inspired by the'mashrabiya, which is the proposed treatment solutions for environmental impact. The building's façade is highly adaptable, enabling it to effectively regulate its inner atmosphere and significantly reduce energy consumption from building services systems [12]. **Application 0f AI** responsive façade by using the'mashrabiya concept, the digital revolution has made it possible to design buildings with dynamic and variable interfaces. The building has a building maintenance unit (BMU). It's a crane that lies above the central core on the roof level of the building and passes inside The roof houses the non-pulse-free power generation necessary for a system, including solar thermal panels for heating. Activates scarecrows with sensors and artificial lights near the ceiling and glass wall. also used alarm systems Fire and surveillance[12]. These applications utilize computer control to effectively respond to ideal solar and light circumstances. This level of achievement, employing a sensor system that integrates advanced digitalization techniques like IOT-BIM, has never been accomplished on such a large scale previously.	This study emphasizes that: AI applications, integrated with IOT-BIM , study building performance, operation, and maintenance systems to predict future maintenance for sustainable maintenance.

2.4.3. Residential buildings in eastern Slovakia,Case Study (3)

Residential buildings in eastern Slovakia is presented in **Table 4.**

Table 4. Case study (3): increase life expectancy in residential buildings

Residential buildings in eastern Slovakia	Data collection and analysis
Design Featuers This study represents the importance of energy impact on sustainable maintenance by linking building life expectancy to energy consumption and emissions across various life scenarios**.** examines the impact of residential buildings in eastern Slovakia on CO2 emissions over 50, 100, and 150 years, using data from eTool LCD, material summary reports, construction budgets, and energy demand calculations[5].	This study emphasizes that the importance of replacing or renovating materials early to improve building characteristics, reduce energy demand, and increase life expectancy, thereby reducing environmental impact.

Modules		50 years kg CO_2e	100 years kg CO_2e	150 years kg CO_2e
A1-A3	Construction Materials	1370900.18	1370900.18	1370900.18
A4	Transportation to site	34596.44	34596.44	34596.44
A5	Construction/installation process	228840.81	228840.81	228840.81
B1	Use Phase			
B3	Repair	0	0	0
B4-B5	Material replacement and refurbishment	145718.08	515502.13	952005.3
B6	Energy use	6137052.55	12274105.1	18411157.64
B7	Water use	338895.78	677791.55	1016687.33
C1	Deconstruction/demolition	19618.68	19618.68	19618.68
	Waste transportation	42571.78	42571.78	42571.78
C3	Waste processing	33863.81	33863.81	33863.81
C4	Waste disposal	280.48	280.48	280.48
D	External impacts (not included in totals)	-1336036.63	-1424539.51	-1550575.31
Total		8352338.59	15198070.96	22110522.45

Impact keys: over 40% (red); 31%-40% (blue); 21%-30% (orange); 10%-20% (yellow)

Fig. 6. Global warming potential impacts for individual phases of building life. whole building during the selected life span[5].

Residential buildings in eastern Slovakia	Data collection and analysis

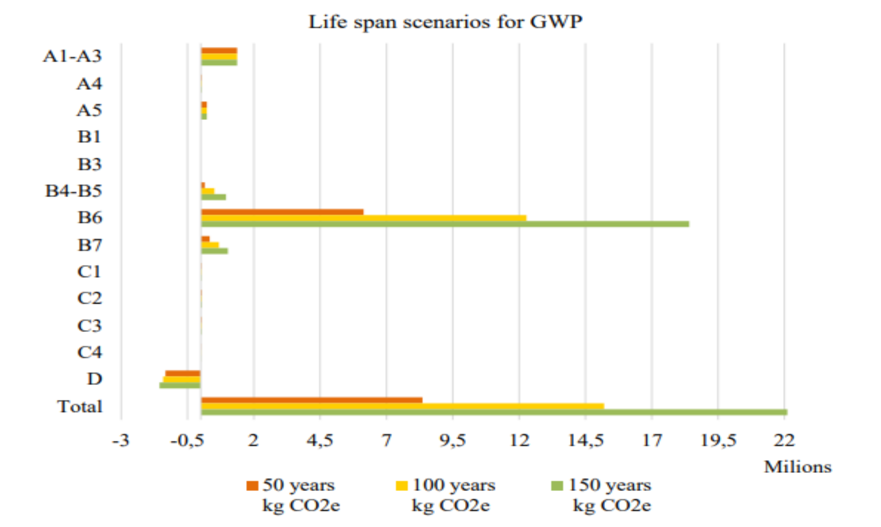


Fig. 7. Global warming potential impacts for individual phases of building life. whole building during the selected life span[5].

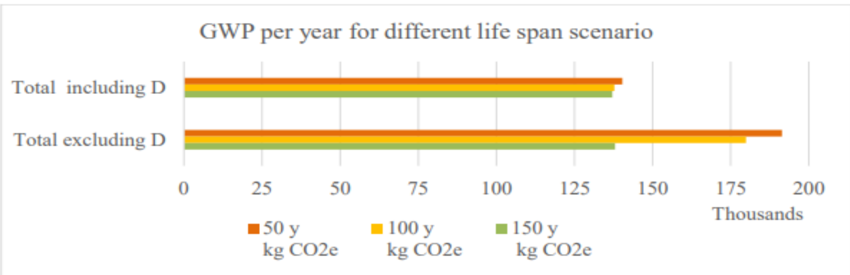


Fig. 8. the CO2 emissions of building scenarios for each result category. Total amount with and without the D module[5].

It suggests that a 150-year-old building produces 12.92% fewer emissions compared to a 50-year-old building.

Result

The impact of a building with a 100-year life span is 81.96% larger than a 50-year life span, with energy use being the biggest contributor to greenhouse gas emissions. The impact of a building with a 150-year life span is 164.72% greater compared to a 50-year life span.

The replacement and renovation category has a growth of over six and a half times in impact, while emissions associated with energy use treble. The study also shows that a building lifespan of 80 years reduces_environmental impact by 29%, 100 years by 38%, and 120 years by 44%.

The impact decreases significantly when considering the D module, suggesting that more attention should be given to reusable or renewable components for buildings with short life spans[5].

2.4.4. The Result

The 150-year-old building produces 12.92% fewer emissions compared to a 50-year-old building. Subsequently, we can improve energy efficiency and user comfort, particularly in HVAC systems, be aware of mandatory building inspections, and apply rehabilitation strategies to address structural deficiencies. Eng ageing in the restoration of ageing buildings is more environmentally beneficial than demolition and reconstruction.

There's a possibility of implementing a sensing system using AI and integrating various advanced digitalization techniques, such as the IOT, (IOT-BIM), to reduce environmental impact and achieve sustainable building maintenance. As explained in Case Studies (1, 2), there's a possibility of using it in residential buildings. As explained in Case Study (3), the life expectancy of buildings, which is presented in **Table 5.**

Table 5. How Case Studies Achieved the Purpose of Research.

The role of AI	
Case study (1) **The City Theatre** Age of the building: 115 years	Case study (2) **Al-Bahr Towers** Age of building: 12 years
Result	**Result**
Application of AI A sensing system is implemented by integrating various advanced digitalization techniques, such as the IOT, edge computing, and cloud computing.	**Application of AI** By sensing systems implemented by integrating various advanced digitalization techniques, such as (IOT- BIM).
reducing environmental impact and achieving sustainable mentainance	
Case study (3) **residential** **buildings in eastern Slovakia**	
Result	
It suggests that a 150-year life span building produces 12.92% less emissions compared to a 50-year life span	Reducing environmental impact
prolonged Assumed Lifespan of a Building	

3.POSSIBLE FINDING AND RECOMMENDATION

Possible findings and recommendations in residential buildings

- Now we realize the importance of replacing or renovating materials early to improve building characteristics.
- Reducing energy demand can reduce building ageing and prolong the assumed lifespan of a building, thereby reducing its environmental impact.
- Clear job descriptions and responsibilities are essential for directing employees and reducing chaos in maintenance organizations.
- Sustainable maintenance is more convenient, reduces costs, and improves user health and safety. The most effective approach is a sustainable approach for the first decade after building handover.
- Stakeholders must receive the maintenance catalogs specified by the housing unit's operating system and the proactive maintenance work to be performed before the building's assets are damaged.
- The 10-Year Guarantee Certificate may be delivered to the owner. by the implementing contractor to ensure that maintenance works are carried out even after the project is implemented.
- Stakeholders should realize how to deal with the various parts of the building, and its appendices in order to achieve the highest performance. by an instruction manual for the user of the unit, specifying the following:
    - Housing unit operating system
    - The specific ages for various parts of the building as (electrical system, drainage system).
    - Instructions of using each devices for the possibility of maintaining their performance throughout their life expectancy.
- Retrofitting strategies for sustainable buildings can improve energy efficiency and user comfort, particularly in HVAC systems.
- Mandatory building inspections can address neglect in older buildings, while rehabilitation strategies address structural deficiencies.
- Eng ageing in the restoration of ageing buildings is more environmentally beneficial than demolition and reconstruction.
- We should apply various building life cycle assessment tools that appeared we were able to identify weaknesses and strengths over the life expectancy of the building, and with those tools, we were able to prolong the building's life cycle by working to scale up those assessments.
- We can apply. The design concept of the building exterior is inspired by the'mashrabiya', a traditional piece in Arabic architecture of wooden lattice screens as a proposed treatment solution for environmental impact to prolong the assumed life span of a building.
- When we apply the significance tool of LCD-LCC-LCA, we can assess the performance of the building in the short and long term. The occupied parts of the building's economic performance and building environmental impact which have the most impact on increasing

the life expectancy of the building by working on those assessments to achieve sustainable maintenance.

- We should apply an AI sensing system that has been developed for long term indoor environmental monitoring to achieve sustainable maintenance in residential buildings.

- The integration of developing technology and stakeholder participation is of utmost importance in order to effectively address both present and future requirements. We should apply IOT-BIM technology and its integration with AI applications as ML, to achieve sustainable maintenance in residential buildings, this will help bridge the gap between sustainable maintenance programs and their actual application.

CONCLUSION

The study emphasized that the applicability of AI offers an effective solution by enabling unsupervised algorithms to efficiently find deviants from a large amount of data. AI is beneficial for both real-time and post-event processing. Where it can be applied to Activate avast amounts of data and have a chance of making sense of the data to bridge the gap between sustainable maintenance programs and their actual application to achieve sustainable maintenance of residential buildings through the implementation of various aspects of sustainable maintenance strategies, in particular the strategy of technical aspects related to the study of IOT-BIM and its integration with applications as ML and the construction ageing strategy related to achieving higher LCD-LCC-LCA values, which serves to prolong the assumed life span of a building, as shown in **Fig. 9.** These results aren't covering the whole picture and sides of this topic. These sides are recommended to be investigated.

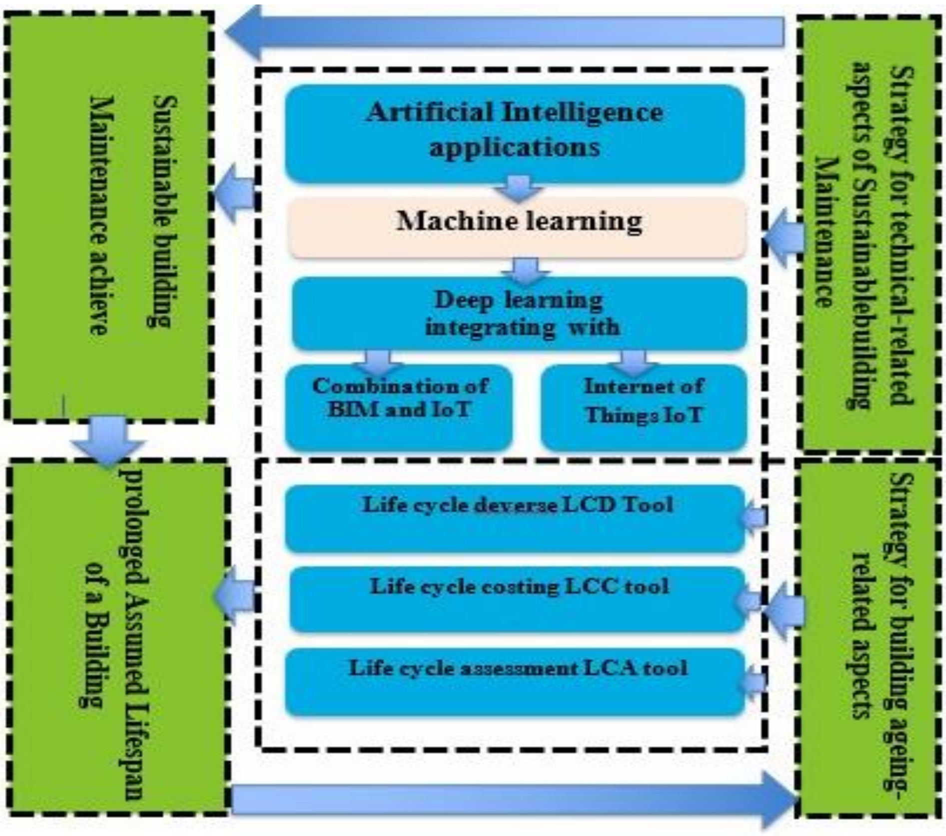


Fig. 9. Achieving of Sustainable Maintenance strategy by application of AI.

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