Applications of Artificial Intelligence Enabled Systems in Buildings for Optimised Sustainability Performance

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Abstract

The building and construction industry has been recognized to be stagnant and slow in the digital transformation. Artificial Intelligence (AI) is at the forefront of transformative information technology, and it offers competitive advantages to the construction industry to be more resilient and sustainable. Despite of this, there is a knowledge gap to identify how contemporary AI practice supports the decision making for creating sustainable buildings and cities. This paper aims to explore the potential areas of AI applications in the built environment for delivering the goals of sustainable buildings and cities. A survey design method was used to investigate AI applications in the contemporary building practice. Surveys were distributed to 100 respondents working in AI technology or service providers by emails and online platforms. AI systems are adopted in the areas of HVAC, water management, smart parking systems, and security and alarm system. Smart vehicle parking system is identified as the main area with wider AI applications, followed by security and alarm system, water management system and HVAC systems. Smart water management systems are identified as a key opportunity area for AI adoptions in buildings and cities. AI enabled systems can improve the efficiency of resources management and optimize the energy efficiency in the built environment. The adoption of AI can assist governance of sustainable building and cities by analysing data and information of a building’s complexity and a city’s dynamics. Apart from the digital transformation, AI also helps to achieve significant contributions in delivering the goals of sustainable building and cities.

1. Introduction

The building and construction industry has been recognized to be stagnant and slow in the digital transformation. Being one of the least digitalized sectors, the construction industry experienced no significant improvement in productivity (Abioye et al., 2021). Researchers attributed this to age-long culture of resistance to change, fragmented and fragile structure, high risk operation and heavy reliance on physical work and human workforce (Abioye et al., 2021). To transition towards digitalization, it is critical to improve the capacities and capabilities of the construction industry to deploy information and communication technology for enhanced efficiency.

Artificial Intelligence (AI) is at the forefront of information technology, and it offers competitive advantages to the construction industry to be more resilient and sustainable. The construction industry can be made "smarter" by adopting integrated intelligence technologies to improve its efficiency and operations. AI is described to be an enabling solution to create sustainable and smart cities by analysing data and information of a building's complexity and a city's dynamics. Despite of a variety of benefits, there has been a low level of AI applications in the Malaysian construction industry. AI is considered relatively new to the construction practice in Malaysia. As mentioned by Mohamed et al. (2021), 33% of the respondents have no experience in AI applications while 32% of the respondents have only 2 to 5 years' experience working with AI applications and equipment. In the meantime, 65% of the respondents described that the level of AI implementations in the construction industry is only 1%-25%.

The low implementation level of AI in the construction and building industry could result from a low level of awareness and knowledge of how contemporary AI practice supports the decision making for creating sustainable buildings and cities. As a result, this paper investigated the potential areas of AI applications in the built environment. The results can give a better understanding about adoption of AI-enabled systems and applications in the buildings. Additionally, the research could also lead to an increase of the usage of AI applications in the building and construction industry for meeting the sustainability goals.

2. Artificial Intelligence

AI is the simulation of natural intelligence processed by the computer system to mimic human intelligence and action (Advani, 2021). It allows a machine to learn, find patterns and correlations, and extrapolate from these by analysing enormous quantities of big data. AI is capable of analysing complex algorithms and self-learning. AI can identify the abnormality more quickly and solve the problem with the least errors. Machine learning and deep learning are subfields of AI and have been employed to tackle complex issues and resolve problems.

The term of AI was described by Marvin Minsky and John McCarthy in the 1950s, who is also known as the father of the field. In 1956, the AI term was coined officially by the twos in Dartmouth Summer Research Project on Artificial Intelligence (DSRPAI) at Dartmouth College, New Hampshire and this marked as the golden age of AI (Haenlein & Kaplan, 2019). However, the idea of a machine can think began early than that in which a British logician and computer pioneer Alan Mathison Turing proposed the ideas of machine intelligence by reference to chess play programming. The period of 1974-1980 was the period of AI winter as the government funding dropped in the field. In the early 2000s, the advent of deep learning and machine learning led to a revolution to advance AI applications in various fields.

2.1 AI-enabled Systems for Sustainable Buildings and Cities

AI-enabled systems are the systems that are known as a 'thinking machine', and are defined as able to think, work and conclude intelligently. It is integrated in the systems and Internet of Things (IoT) to perform beyond human's capability without supervision of humans. AI plays a role in the service and maintenance of a building. Ahmad et al. (2016) reported that 40% of global energy consumption is contributed by building. Meanwhile, 30% of carbon emission is generated by building. To make the built environment more sustainable, AI can enable smarter solutions to improve efficiency and operation in the building systems.

Buildings are now gradually incorporated with AI to make the building management systems more responsive to the occupants' requirements. A building integrated with AI applications is perceived to be able to automate the building system and solve the problem of human beings systematically. AI has the potential to improve occupant experience, increase energy efficiency and optimise the performance of buildings as AI can make effective use of huge amounts of data and analyse them quickly and accurately. AI-supported facilities can help reduce energy consumption by providing a more efficient building management, thereby resulting in a reduction of energy and operation costs.

A smart building is an essential component for building a smart city, and AI plays a critical role in delivering the mission of smart and sustainable cities. By processing a large quantity of big data, AI can generate better data prediction, hence offering solutions to support sustainable technologies and systems in the built environment. With the use of AI, programmed tasks and actions can be carried out at scale and at low cost. More possibilities of outcomes can be explored to identify the best solutions for the targeted building issues. The subsequent section examines various applications of AI enabled systems in the building or city context to aid the decision making for sustainability.

2.1.1 Heating, Ventilation and Air-conditioning (HVAC) system

The HVAC system is described as a major area that generates the most energy consumption in a building. Research shows that HVAC system incorporated with AI has an ability to control the airflow required within a particular space, leading to less energy used. As illustrated by Cheng et al. (2019), AI assisted HVAC achieved 14.4% in the estimated average energy savings percentage and 44.04% in the maximum saving ratio.

Intelligent controllers have been widely used in s AI enabled HVAC system. As stated by Mirinejad et al. (2012), an intelligent air conditioning system is controlled by Fuzzy Logic Controllers (FLCs). A fuzzy controller is integrated with Knowledge Base (KB) that is supported by if-then rules (Rule Base), membership functions (MFs), scaling factors (Data Base). The performance of KB is designed based on human experts instead of the mathematical model of the system. KB is capable of improving the performance of traditional controllers and minimising errors between the outputs and the targeted values where the traditional proportional–integral–derivative (PID) controller can not perform. The main difference between intelligent controllers and conventional controllers is that no mathematical modeling is required to create the controller. Intelligent HVAC systems generally involve a large amount of data input. Four sensors are present within AI assisted HVAC systems to receive input variables such as user temperature room, temperature difference, dew point and electricity volt. Those inputs are then managed by the fuzzy logic control through fuzzification, inference and defuzzification. Hence, the outputs will be determined and the system to be controlled with four parameters which are compressor speed, mode of operation, fan speed and fin direction. With the presence of FLCs, the performance of HVAC systems can be optimised, leading to significant energy savings and enhanced thermal comfort.

On one hand, Alcala et al. (2009) suggested the use of new tuning techniques to improve the behavior of FLCs applied in the HVAC systems. The classical approach is not able to obtain the global configuration due to a large and complex search space, hence affecting the system performance. Lateral tuning can resolve the issue by reducing the search spaces that emphasize the MF support position only. This technique eases the system readability and reduces deviation as one or two parameters per label are considered. Alcala et al. (2009)'s work also showed a positive synergy in which the combination of rule selection methods with tuning techniques helps to enhance the performance of HVAC systems. By incorporating rule selection in tuning techniques, unnecessary and redundant rules that may produce bad performance can be removed, thereby giving a more compact and accurate FLCs.

On the other hand, He et al. (2014) also found a new AI enabled approach to decrease the consumption of HVAC system consumption within buildings. Three computational algorithms - evolutionary algorithms (EA), a particle swarm optimization (PSO) and a harmony search algorithm (HS) were proposed, and 300 combinations of parameters settings were developed for each of the computational algorithms. The performance of each algorithm (depends on the parameters settings) was subsequently evaluated by computing five selected computational instances from the dataset. Energy saving was recorded since computational algorithms can optimise the two set points in the system - supply air static pressure set point and discharged air temperature set point.

2.1.2 Vehicle Parking System

AI can be integrated into vehicle parking systems to make them more secure and intelligent. An AI enabled parking system offers more efficient management services to users. With the integration of wireless communication, sensor technology devices, and a smart management system, AI parking system can determine the utilisation rate of parking space and enhance the user's experience by obtaining real-time data regarding parking availability (Wang and He, 2011).

According to Ruili et al. (2018), smart parking systems use image processing and AI to recognise vehicles. Node-Red and Open ALPR are used as a recognition tool for programming purposes. In Ruili et al. (2018)'s study, the proposed system can automatically arrange a car park for drivers by considering the current traffic flow, the distance to reach the suggested car park, the previous records, etc. With the Noted-Red and Open ALPR, it ensures the camera obtains the correct information while the car park has completed parking. The car plate number will be captured by the camera and recognise the car plate number. Each of the car's numbers will be bound to the app on devices. The information will then be delivered to the Information processing central system, hence the time and the price will automatically be calculated. Within this system, an ultrasonic sensor is presented to recognize whether the car is parked or leaving. It benefits the driver who can only pay the fee for the time that car has parked. By implementing a smart parking system, the user can directly pay their parking fee on their devices.

In Souza de Castro (2017)'s study, a multiagent system (MAS) was developed to allocate spots in a smart parking system based on corresponding degree of trust of users. This system consisted of two types of agents who are drivers and managers. Driver agent aims to find and obtain a spot whereas the manager agent is responsible for administering the smart parking. In this research, every user has their own trust degree values. The user with a high value of trust degree is able to get a spot within a shorter waiting time compared to the lower trust degree value users. On the other hand, Kumar et al. (2017) has proposed a smart parking system using Radio Frequency Identification (RFID) and Global System for Mobile Communications (GSM) technology. The combination of the transceiver and antenna within the RFID system is capable of tracking the moving objects with a high accuracy. Check-in and check-out of the vehicles are controlled by identifying the member ID and analysing the database. If the ID is not present in the system, the security alarm would react to the situation immediately to prevent theft from entering the building.

2.1.3 Security and Alarm System

The purpose of security alarm systems is to offer warning signals and threatening information to alert owners of danger. As mentioned by Ahmad et al. (2019), it is very essential to protect the building by implementing the advanced security alarm system due to the increasing crime rate over the world. Generally, within a security alarm system, multiple sensors will present to detect the abnormal and trigger the alarm (Mahmud et al., 2006). In Artem et al. (2017)'s work, a security system has been mentioned by using machine learning methods. The artificial intelligence algorithm is used to make automatic decisions of illegal penetration. With the measured data of face recognition, machine learning algorithms help to calculate the presence of occupants based on several parameters such as day of week, electricity consumption and car presence. The probability of occupants' presence in the building will be developed through the artificial neural network. After processing, the system is able to detect the intruder based on the measured values. Automatic decisions of illegal penetration will be made and act upon this situation to minimise the damage of the building.

Liang and Tian (2016) have proposed a multi-sensor fusion approach for fire alarm systems by using the back propagation (BP) neural network. The system has been improved by integrating two or more sensors, leading to offer a more accurate and reliable approach compared to the conventional system that uses a single sensor. In this system, three sensors are presented which are temperature sensor, smoke sensor and CO concentration sensor that is collected by neural network. If one of the sensors exceeds the threshold value, the data fusion center will continuously iterate the sensors. Based on the collected fusion data and signal given, the final decision can be generated to act upon the situation.

2.1.4 Water Management System

Traditional complicated water issues such as water shortage, water deterioration and aging water infrastructure system has called for smart water systems. Smart water systems have played a role from storing to delivering and consumption. Smart components such as sensors, controllers and data centers have existed and technologies such as automated control technology (ACT) and information communication technology (ICT) have been applied in the smart water system to address and monitor appropriately the water consumption, track the water leakage and pipe burst issues (Li et al., 2020). Additionally, real-time measurement is offered which can be applied in water pumping, valve operation and scheduling. Smart water system optimizes the use of water consumption, offering cost-effective and achieving sustainable criteria. A smart water management system is the water supply process which is integrated with technologies in terms of hardware, software and analytics which assists the water supply to solve problems through automation, data gathering and data analysis. Hope et al. (2011) defined that smart water system is a new approach to offer water security with considering significant future risks in terms of population growth, hydrological variability and extreme events and intensifying water allocation demands water across every sector and industry. According to Kim (2019), SWS offers a more resilient and efficient water supply which may result in reducing cost and enhancing sustainability.

In Nguyen et al. (2017)'s work, an intelligent water system is proposed which is called Autoflow©. Within this system, it consists of several smart algorithms to operate which are Dynamic Time Warping, Hidden Markov Model, Dynamic Harmonic Regression and Artificial Neural Network. These components are presented for autonomous water end use classification which offer the data information to determine the water consumption of an individual household based on where, when, how and why the water is used. On the other hand, this system also includes dynamic Harmonic Regression, Kalman Filter and Fixed Interval Smooth algorithms which are objective for short term water demand forecasting. Autoflow© was developed to provide the tables of water consumption in an individual's household. Hence, the users are able to refer to their daily, weekly and yearly water consumption and avoid the bad habit of consuming water. Through the system, a water demand management strategy can be established for the water consumer. In Sanz et al. (2012)'s study has been proposed Fuzzy Inductive Reasoning (FIR) to detect the water leakage problem. Two sensors which generate pressure values have been used and located at two different areas which are District Area, Nova Ica`ria in Barcelona. The FIR process is divided into four main stages which respectively are fuzzification, qualitative modeling, qualitative simulation and followed by defuzzification, hence the predicted value can be generated. In this study, each model is compared with the real data. The results showed that increasing the number of faulty fuzzy models leads to better performance of the leakage detection, where presents a good precision when detecting the leakage with high accuracy.

3. Research Methods

The research employed a survey design to investigate AI applications in the contemporary building practice for sustainable buildings and cities. Likert scale questions and multiple choices questions were developed to examine the extend of the implementation of AI systems in buildings and cities. Participants were asked to complete a questionnaire to identify the prevalent areas of adopting AI applications in buildings for meeting the sustainable development goals. The targeted respondents were AI technology or service providers in Malaysia. Surveys were distributed to 100 respondents in AI technology or service providers by emails and online platforms. A total of 35 responses were received where respondents who have no relevant work experience with AI were excluded from the study. The collected data were then analysed using descriptive analysis and Relative Importance Index (RII). RII was used to rank the factors or variables according to their average score. The average score can be calculated using the formula below.

$$\text{RII} = \frac{\sum W}{(A\ x\ N)}$$

Where W- weightage given to each factor, ranging from 1 to 5

A – The highest weight

N – Total number of respondents

4. Results and Analysis

All respondents have relevant experience of working with AI enabled systems but there were almost half (43%) of the respondents with less than 1 year experience in AI technologies and services. Majority of respondents revealed their organisations own less than 10 types of AI systems in their organisations. This showed that the market of AI applications is less mature and there could be a limited range of AI technologies and service in the market.

The results found that the most common areas for AI-enabled systems is smart vehicle parking system, with RII of 0.731. This is followed by security and alarm system (0.68) and water management system (0.669). Surprisingly, AI-assisted HVAC systems scored the lowest RII rating (0.646). Smart parking system is ranked the highest since most of commercial buildings in Malaysia employed smart parking systems to assist users in finding a car park spot. The use of smart parking system can be noticed in several renowned shopping malls in Malaysia. To maintain a good flow of visitors, the operators of shopping malls incorporated smart parking systems to assist users to find car spark spaces during the peak seasons or periods. The results illustrated that all four AI application areas were found to have a relatively high RII score, all scores in between 0.64 to 0.68. This presents that the adoption of AI systems is not new to building users. People are open to adopting AI systems in buildings to aid their decision making in building administration and operation.

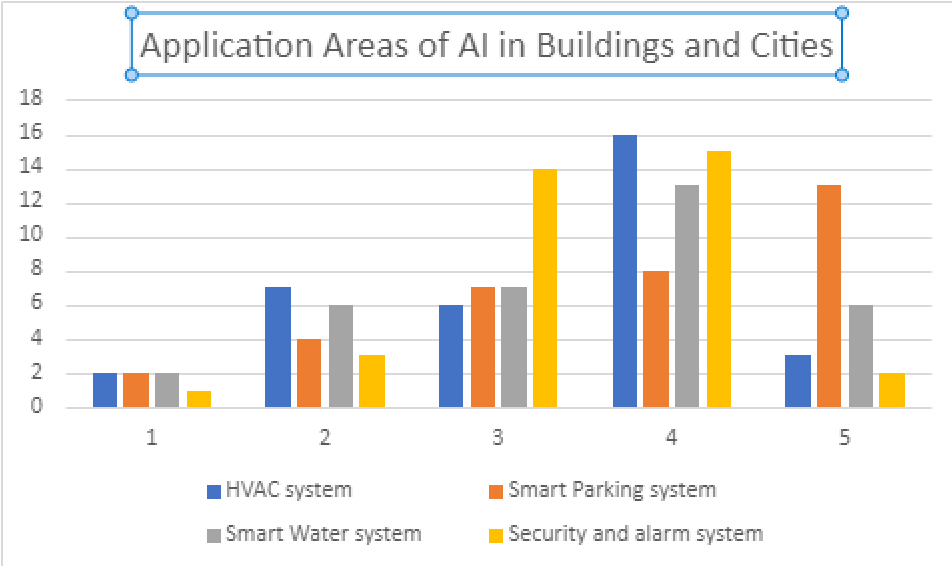

Figure 1 Application areas of AI enabled systems in buildings and cities

Participants were asked to identify the opportunity areas in which AI systems shall be incorporated for an increased adoption in buildings and cities. Smart water management system obtained the highest score with a percentage of 34.29%. As mentioned by Shanmugam et al. (2021), some states in Malaysia such as Klang Valley regions faced water disruption issues in the past few years, and this posed great difficulties to communities to maintain their daily routines properly. There are also water contamination issues in certain parts of Malaysia where users may not get clean water supply. The quality of water supply also raised a concern to people because filtered water from the water treatment centre still fails to meet the good water quality standard. It gives an urgency to develop AI assisted water management system to resolve water issues in the regions. AI can collect and analyse big data from day-to-day operations to examine the water quality for safe use. Data collected from sensor readings can also be integrated into AI systems to monitor the usage of water and determine the water quality. Smart parking system is ranked the second opportunity areas (31.43%) for AI applications as there is a concern for vehicle security due to the high rate of car theft case (up to 314 cases per 100,000 population in Malaysia). HVAC system and security system with a frequency of 7 and 5 responses and a percentage of 20% and 14.28%.

Table 1 Opportunity areas of AI systems

AI Systems	Percentage
HVAC system	20%
Smart parking system	31.43%
Water management system	34.29%
Security and alarm system	14.28%

5.0 Discussion

Smart parking systems (RII =0.731) and security and alarm system (RII =0.680) are the most common AI applications in Malaysia, followed by water management system (RII =0.669). The AI assisted HVAC system is found to be the least common system (RII =0.646). The result is out of the expectation in view of a wide adoption of HVAC systems in the Malaysian buildings. HVAC is a main building system as Malaysia is a hot and humid country which directly increases the adoption of the HVAC system. It should be widely installed in buildings and housing to reduce carbon emissions. On the other hand, smart water management is the highest potential area for AI-enabled systems to explore in built environment. the flooding problem is increasing rapidly in recent years. It brings a negative impact on every individual's daily life financially and physically. Moreover, inconsistent water supply happened to the states of Selangor and Negeri Sembilan regularly, leading to the residents having to use the water from the nearby river. United Nations has stated that water scarcity will affect approximately 20% of the human population in 2025. Hence, it is necessary to have exposure on AI enabled water management system to reduce the impact of the flood. The smart water management system with the combination of IoT, big data, and AI technologies are recommended to be used in Malaysia. By utilising learning algorithms, the sensors are able to control the supply of the water, monitor the usage of the water and create a forecast for future consumption which results in achieving sustainable and budget goals for a building.

The findings shows that all four application areas of the AI-enabled systems are said to be important to realise the goals of sustainable buildings and cities. HVAC systems (RII= 0.777), smart parking systems (RII= 0.846), water management system (RII= 0.817) and security and alarm systems (RII= 0.869) are found to score high scores (all with a value above 0.7) for delivering sustainable development goals in building and cities Except for security and alarm systems, the rest of AI-enabled systems contributed to energy saving and carbon emission reduction. Transformative technologies such as AI are not only important for the digital transformation of the construction industry but also has a pivotal role in delivering the goals of sustainable building and cities.

6.0 Conclusion

The adoption of AI enabled systems can aid the decision making for sustainability in buildings and cities. There are four common areas of AI applications, i.e. HVAC, vehicle parking systems, water management systems and security and alarm systems. The results found that smart vehicle parking system is more widely adopted, followed by security and alarm system and water management system and HVAC system. Smart water management is recognized as the most important opportunity area for AI-applications in the built environment, considering frequent water disruption and water quality issues faced by the people in the recent years. AI enabled systems can improve the efficiency of resources management and optimize the energy efficiency. The adoption of AI can assist governance of sustainable building and cities by analysing data and information of a building's complexity and a city's dynamics. Apart from the digital transformation, AI also helps to achieve significant contributions in delivering the goals of sustainable building and cities.

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