The Integration of 3D printing, Artificial Intelligence and Internet of things for Construction of Sustainable Smart Homes

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Abstract

The field of construction is undergoing exponential transformations and innovations as a result of technological advancement in the field of hardware, software and Artificial Intelligence (AI). Several architectural and construction firms have adopted innovative technologies to make construction easier, sustainable, efficient, cheap, fast, low generation of waste etc. The increase need of smart homes equipped with sensors that can sense and regulate temperature, prevent or control fire, sense gas leakage, motion detectors and alarms for security and other application is in high demand. These types of smart homes can only be achieved by integrating different technologies together which include 3D printing, artificial intelligence (AI) and Internet of Things (IoT). Despite the growing research in the field of automated construction, there are few articles that attempt to integrate these technologies together for futuristic smart homes and potential of smart cities. Thus, this study is aim at providing up-to-date advancement in technological innovation within the construction sector with regards to applications of 3D printing, IoT, and AI. In this review article, we discuss the need for 3D printing in construction, advantage and disadvantage of 3D printing, Artificial Intelligence (AI) and Internet of Things (IoT) and the application of these technologies in addressing challenges regarding 3D printing and promoting sustainability in the construction industries.

Keywords: 3D printing, IoT, AI, Construction, Smart Homes

1. Introduction

Construction industry is one of the industries that is highly concerned with safety which contribute to its slow adoption of new technologies. The risk associated with the industry is critical to implementation of newly developed or inventing method and products which are untested or required continuous evaluation and regulation for approval (Allouzi et al., 2020). However, many scholars perceived that conventional construction which revolves around the use of manually operated equipment or tools and traditional construction approach has reach it technological peak (Mydin et al., 2014; Hager et al., 2016).

As a result of technological advancement in the field of construction, conventional or traditional construction approach lagged behind in terms of customers' core standards of quality, cost, and timeliness (Bock, 2015; Wu et al., 2016). In comparison to other industries, the construction industry saw a decrease in productivity, reduced in profits margins. Moreover, even though with the increase in population and demand for houses, building standard houses from scratch is expensive for average working class and also the fear of mortgage by the general public which contributing to the stagnating productivity of the industry (Aghimien et al., 2020).

The advancement in science and technology has led to several scientific innovations. In the field of civil engineering, 3D printing of building has been trending throughout the 21st century. Consequently, while still in its infancy, 3D printed construction is perceived as the promising technological advancement with the potential to revolutionize the construction industry. 3D-printed construction is regarded as an advanced construction approach which use machines and additives for construction of wide range of complex geometries and building structures without the need of framework based on layer-by-layer material deposition approach (Biernacki et al., 2017; Sakin and Kiroglu 2017).

Construction of smart homes is another area that receive tremendous attention and become a prominent area of research in the last few decades. “The concept of today’s fiction is tomorrow’s reality” is evident in the case of smart homes as a result of technological advancement in the field of sciences and engineering. The integration of automation using internet such as internet of things (IoT), Industrial Internet of things (IIoT), AI and material science are the main drivers of smart homes. Smart homes or home automation revolves around the monitoring and controlling of home devices and appliances remotely using IoT-based systems (Agarwal et al., 2019). The major challenges facing these sectors revolves around the need to improve safety and efficiency of IoT devices, promote the adoption and implementation of 3D printing and the need for huge amount of data that can be used to feed artificial intelligence models. The framework of this study is presented in figure 1.

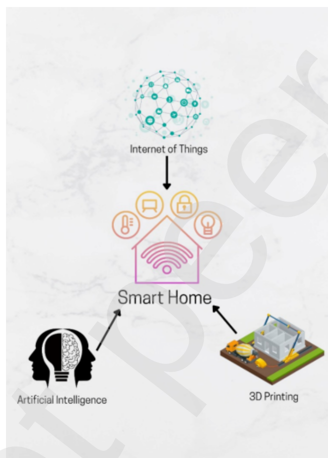

Figure 1. Framework

1.1 Literature Search

The literature contains hundreds of articles that comprise the review keywords. The initial choice of articles to be included in this review was created using Google Scholar search for articles with the following keywords or phrases:

3D printing, 3D printing in construction, Factors affecting 3D printing, Artificial intelligence, Machine Learning, Internet of things, application of Artificial intelligence/Machine Learning in 3D printing, application of Internet of things in 3D printing

We have reviewed 123 total articles in which majority from top journals and publishing platforms such as ScienceDirect, Springer, IEEE, Frontier, MDPI, Taylor and Francis, Hindawi etc. 100 of the articles are from 2015 and above, 23 are below 2015 and 4 from website. Some of the criterial for selection include articles that are sound in terms of scientific contents, peer reviewed, written in English and assigned with DOI number except. Among these articles 30 discusses about 3D printing, 3D printing in construction, factors affecting 3D printing. 34 discusses about artificial intelligence (definition, types, supervised, unsupervised and reinforcement learning,). 20 articles focus IoT, definition, component, classifications and application. 40 articles provide the literature for the integration of 3D printing, AI/ML and IoT in smart buildings. The summary of literature search is presented in Table 1.

Table 1. Summary of Literature search

Classification	Number
Articles from 2015 upward	100
Below 2015	23
With DOI number	112
Without DOI number	11
Review and Research articles	111
Conference articles	12
Online sources	5
Introduction	9
3D printing	30
AI/ML	34
IoT	20
Integration of technologies in smart home	40

Table 2. List of Abbreviations

Abbreviations	**Full meaning**
AI	Artificial Intelligence
AM	Additive Manufacturing
BIM	Building Information Modelling
C3DP	Construction 3D Printing
CC	Cloud Computing
COVID-19	Coronavirus Disease 2019
CPU	Central Processing Unit
DA	Data Analytics
DCP	Digital Construction Platform
DMD	Direct Metal Deposition
DT	Decision Tree
FDM	Fused Deposition Modelling
FoF	Factories of the Future
GBM	Gradient Boosting Machine
GHG	Green House Gases
GMM	Gaussian-Mixture Model
GPS	Global Positioning System
HL	Hidden Layer
ICT	Information Communication Technology
IIoT	Industrial Internet of Things
IL	Input Learning
IoMT	Internet of Medical Things
IoT	Internet of Things
IoNT	Internet of nano things
IoTH	Internet of Things Health
KNN	K-Nearest Neighbors
MAPE	Mean Absolute Percentage Error
MC	Monte-Carlo
ML	Machine Learning
MSE	Mean Squared Error
NASA	National Aeronautics and Space Administration
NBC	Naïve Bayes Classifications
OL	Output Layer
PCA	Principal Component Analysis
RF	Random Forest
RFID	Radio Frequency Identification
RL	Reinforcement
RMSE	Root Mean Squared Error
SDGs	Sustainable Development Goals
SLA	Stereolithography
SLS	Selective Laser Sintering
SVM	Support Vector Machine
UN	United Nation
WSNs	Wireless Sensor Network
VULMA	Vulnerability Analysis using Machine-learning

1.2 Research Motivation and Contribution

The motivation behind this article comes from the goals set by the research center of for AI and IoT, Near East University in promoting the applications of automated innovative technologies in different disciplines such as medicine, smart homes, smart cities, smart grid, agriculture etc. As automated constructions are perceived as drivers of smart homes, consequently, smart homes are regarded as units of smart cities. Constructing smart homes require the integration of several technologies, among which 3D printing, AI and IoT are recognized as crucial ones. Thus, this article is aim at providing up-to-date state of art of innovation in the building industry, as well as pros and cons of these technologies in advancing smart homes.

This article only intent to overview how smart and innovative technologies are fostering or helping in realizing the dreams of smart homes. In addition, this article does not cover extensively on smart cities, rather it is focus on smart homes which are regarded as one of the units for realizing smart cities. Thus, this article stands to provide extensive and broad overview for researchers in different fields such as architecture, Civil engineering, Computer science and AI as a summary of concepts and applications of emerging technologies in the context of smart buildings. Therefore, this article is set to contributes the following aspects:

1. To provide both researchers and professionals in relevant field of Architecture, Civil engineering, Construction management, Project management, Computer scientists etc. with holistic overview of applications of emerging technologies in promoting smart buildings and smart cities.
2. To explore the gap in the current state of art by focusing on literature that discuss the current and prospect of these technologies in construction industry.
3. To provide an overview of components and classifications of these technologies and their applications in different disciplines.
4. To identify challenges and limitations of applying these technologies in the construction and building industry such as security issues and limiting manpower.

The reminder of this article is structured as follows: Section 2 discusses about 3D printing, 3D printing in construction, factors affecting 3D printing and advantage and disadvantage of 3D printing in construction. Section 3 provides a brief introduction to the concept of AI, Machine Learning (ML), classifications. Section 4 discusses about IoT, significance of IoT, components, working principle and applications. Section 5 overview research articles that discusses on the on application of AI/ML, 3D printing and IoT in construction and building smart homes as well as challenges facing the integration of smart technologies in construction. The article is concluded in section 6, highlighting the need of these technologies, as well as the current challenges and future directions in both academic and commercial settings.

2. 3D Printing

The construction industry has been relying on conventional and traditional approach for construction of buildings such as apartment, estate, hotels, cinemas, places, museums, sport complex centres, religious centres, schools, hospitals etc. Through the last century, there have been progress and advancement regarding tools utilize for construction such as mixing machine, painting machine, cementing machine etc. However, even with these advancements the challenges of automated construction from 2D framework to completion still have a long way to go (Rahman and Omar, 2006).

Construction industries have been associated with large-scale production of waste, the use of non-renewable energy and emission of Greenhouse gasses (GHG) which had effect on climate change and global warming. The increase demand for urbanization and rehabilitation is one of the factors that contribute to increase in massive scale construction globally (Pessoa et al., 2021). The use of conventional building techniques couple with uncertified builders and climatic conditions has led to construction of houses susceptible to collapses, destruction and buildings of low quality in terms of structure and material use. Moreover, conventional building requires massive labour which is expensive as well as longer construction duration and high production of waste (Zhou and Lowe, 2003).

The Key challenges facing building and construction revolves around the use of suitable materials, the desperate need to build faster, stronger, efficient, less susceptible to weather and climatic conditions and natural disasters has led scientists and engineers from different field such as Civil engineering, Architecture, Material science, Computer engineering and AI to developed a 3D printing system which has the potential to replace conventional method (Buchanan and Gardner 2019). The invention of 3DP known as additive manufacturing (AM) has bridged the gap between conventional construction and an optimized automated-oriented approach (Pessoa et al., 2021).

The integration of 3D printing in construction is facing several challenges such as lack of creating awareness to both public and construction workers, lack of government support and policies, lack of practical implementation and research on real implementation of 3D printing construction methods (Berman, 2012; Ng et al., 2015; Dickinson, 2018). Among the Sustainable Development Goals (SDGs) of the United Nation (UN) 2030 agenda is to promote the implementation of infrastructure and services in the construction sector in order to address issues such as emission of GHG, generation of solid waste, large consumption of energy and depletion of water resources. However, one of the feasible approaches to confront these challenges is the integration of innovative engineering based on material science and information technology. The invention of 3D printing of materials has gained attention in the last 2 decades from several disciplines such as additive industries, healthcare sectors, artistic and monuments, construction and architectural firms (Sing et al., 2021). The technological boom as a result of internet of things (IoT) and cloud computing is revolutionizing industries. Thus, merging these technologies with 3D printing has potential in addressing some of these challenges as well as enable digital construction of buildings.

The concept of 3D printing has become a topic of discussion in many scientific platform and news outlets throughout the 21st century. Initially, 3D printing is developed mainly for prototyping projects and products. The invention of 3D printer is dated back to 1986 where the first 3D printer is developed by Charles Hull, but recently, 3D printing technology have been repurposed to development of mainstream products in different sectors and industries. The technology has found its application in different field such as medicine (printing drugs and organs such as teeth and bones), bioengineering, aviation, food processing, tool designs and currently the construction industry. Merging different technologies and fields has changed the landscape of construction industries (Sun et al., 2015).

The mechanism behind Stereolithography (SLA) revolves around the usage of materials (e.g., liquid resin) which is converted to solid material using high-powered laser. The concept of SLA which falls under additive technology involves production of products from the bottom-up through formation of layers. However, even with the advancement in technology, SLA is still among the most popular 3D technologies utilized for formation of parts of products. Apart from SLA, Direct

Metal Deposition (DMD), Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS) are some of the popular additive technologies (Horvath 2017; Dikova, 2019).

3D printing technology relies solely on computer pre-edited operation or set of instructions to create a digital model of desired product where the 3D printer prints the product layer by layer according to the model. 3D printing technology has proven capable of processing cements and printing walls with potential of reshaping construction industry (Ma et al., 2018; Zhang et al.,

2016).

2.1 Advantages of 3D Printing Technology in Construction

Construction industries have been facing challenges in terms of pressure to meet up deadline, utilize resources and maximize profits (Alaloul et al., 2014). To address these challenges, construction companies invested millions of dollars yearly to modify tools and equipment or invent new innovations. With all the advancement in the sector, 3D printing technology is revered due to its potentials to offer solutions to majority of the setbacks, increase efficiency and safety in the construction sectors. Construction 3D Printing (C3DP) as branch of 3D printing has attracted so many scholars' interests in the recent years. However, compared with conventional building approach and prefabricated building approach, C3DP displays many advantages which include cheaper construction, sustainable and durable construction, improved safety, reduced reliance to human resources (e.g., labour), reduced material uses and construction waste, better branding and market share (Camacho et al., 2018; Rayna and Striukova 2016; Al-Rashid et al., 2020; Singha, 2021).

Integration of 3DP in technology has solved so many challenges faced by construction engineers such as less construction time and waste, minimum human errors, sustainability, etc. as shown below:

Design freedom: Unlike conventional approach that limit design freedom, 3D printing technology offers viable design freedom which allows creative innovation. 3D concrete printing enables construction engineers to engineer different shapes that can be bended and structured in different angles (Yang et al., 2019).

Sustainability: Construction of sustainable buildings has been one of the key goals of construction industry. Majority of developed countries mapped out their future goals for sustainable megacities, bridges, roads, tunnels etc. These future goals can only be attained using 3D printing technology which can withstand extreme weather conditions and can operate for days without resting. Moreover, fabrication of building using aluminum silicate can resist earthquake of less than 8 magnitude. Thus, automation of construction has become a field where many construction companies invest in with a dream of making buildings easy to constructs, less errors and sustainable. The use of 3D printing in construction has led engineers to fabricate walls using technical materials such as the building walls using a printable one-component geopolymer mixture of aluminosilicate which contribute to the wall resistance to environment and extreme weather (Maier et al., 2011; Furlani et al., 2018; Yang et al., 2019).

Affordability: Printing houses using 3D printing technology has shown to be cheaper compare to conventional building. Currently, construction of printed houses cost averagely 4000 dollars in Germany, Netherlands, USA and China depending on size and requirements. The reason behind the low cost of constructing houses using 3D printing technology is associated to speed, low requirement of extensive human labour, reduced material use and construction waste (Al-Rashid et al., 2020; Singha, 2021).

Speed: Meeting up deadline has been a major challenge due to shortage of resources or man power in the construction industry. However, the advent of 3D printing technology has shown that small-size homes can be built from ground up to completion in days and large scales buildings in weeks. This shows that 3D building outpaced conventional construction in terms of construction duration which takes months to years. 3D printing technology has shown to save more than 60% of the on-site time spend and minimize more than 70% labour. The use of 3D printing technology has been successful for building blanks of 10 villas in China in the year 2014 within 24 hours with less construction waste compare to traditional building approach (Yang et al., 2019).

Minimize human errors: Among the major challenges of conventional construction is as a result of shortage of labour or unskilled labour which increase human errors (Cai et al., 2019). Human errors in construction have shown to be fatal causing many destructions and deaths throughout history. Building houses through conventional approach is more susceptible to errors. Unlike the use of 3D printing technology which is more accurate and precise due to it automation and programmability. Another disadvantage of conventional approach is the high risk of accident and death among workers. It was estimated that more than 5,000 constructions workers die every day. Thus, the use of 3D printing will save lives, prevent injury, accident and fatalities (Yang et al., 2019; Hossain et al., 2020).

***Minimize labour*:** Construction sector is one of the sectors that need effective man power for its operations. Payment of labour has shown to stretch out budget of companies and minimize profit return. Nevertheless, human errors have caused fatal destruction and injuries to both house occupants and laborers. The invention of 3D printing has shown to minimize labour by a high margin (80%) which makes houses cheaper and maximize profits for construction companies (Tay et al., 2017; Yang et al., 2019).

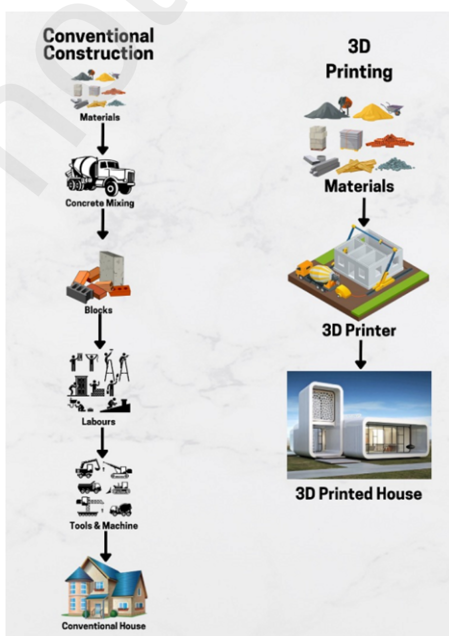

Figure 2. The advantage of 3D printing compared to traditional building

Waste reduction: Construction industry is among the leading industries that produce tons of waste every year. It was estimated that the industry produces more than 1 billion tons of waste on yearly basis and the number is project to double by 2025 to 2 billion tons. Maximizing waste and saving resource is one of the goals of every construction company. Hence, unlike conventional construction that produce tons of waste, 3D printing can minimize construction waste and manage resources. This is possible due to the facts that 3D printing machine is an additive technology that only utilize calculated usage of materials for creating structures and parts (Yang et al., 2019). The advantage of 3D printing compared to traditional building is shown in Figure 2.

2.2 Disadvantage of 3D building

3D printing technology has shown to be the main driver of construction industry in to the future of automated and smart buildings. Despite all the advantages and the prospects of the technology, it is clouded by some challenges which may hinder the attainments of its full potential. Despite the advantages and benefit of 3D printing mentioned above, the technology has some challenges which includes concern on employment, high cost of the printing machine as well as experts who can operate and maintain the machine as discuss below:

High cost of 3D printing machine: Despite the fact that constructing buildings using 3D printing technology is cheaper than conventional approach, however, purchasing the machine and its installation on construction site is very expensive in terms of purchase and renting and can only be afforded by rich firms. Moreover, the cost of maintenance and materials is expensive which makes it difficult for construction professionals to justify the use of the technology to replace conventional approach (Qui 2018).

Increasing rate of unemployment: The global COVID-19 pandemic has led to massive unemployment and one of the sectors that is hit hard is the construction sector due to suspension of works as a result of lockdowns. Apart from the pandemic, construction industries harbor many professionals who depends on the industry for livelihood. However, the adoption of 3D printing in construction is set to minimize human labour which will lead to massive unemployment (El-Sayegh et al., 2020).

Shortage of professional operators. Even though 3D printing technology is set to replace human labour, however, one of the limitations of the approach is the shortage of skilled professionals who can operate the machine effectively and its maintenance. Thus, there is high demands for skilled operators that can operate the machine without causing damages (Tay et al., 2017; El-Sayegh et al., 2020).

Fear*:* For every advent of technology, it comes with fear from the general public. The general public is usually slow to accept technology due to the fear of using computer aided technology in place of humans. In recent years, both professionals and general public have raised concerns over the use of 3D printed building. Many scholars highlighted that the technology need time and assessment before it will be deemed safe and viable (Tay et al., 2017).

Regulations: For 3D technology to become widespread, it has to undergoes several regulations in terms of safety. The buildings have to undergoes several tests over years for it to be deem safe and viable for construction of public buildings. Even though some countries have taken steps to regulate it, it still hasn't fully impacted the construction sector. Currently, there is ongoing awareness about the benefit of 3D printing technology in construction sector, however, its adaptation is highly dependent on laws and regulations of states and countries (El-Sayegh et al., 2020).

3. Artificial Intelligence (AI) and Internet of Things (IoT)

3.1 Artificial Intelligence (AI)

The prospects and concepts of AI have been buzzing throughout the last 5 decades. Definition of AI has been subjected to debate and variations from several scholars. Thus, this led to so many definitions. AI can be defined as a branch of computer science that is concerned with the development of computers that can imitate human-like features such as reasoning, learning and solving problems. The definition of the concept has undergone several modifications over time, one of the recent definitions of AI is termed as any technique that enables computers to mimic human behavior or a branch of computer science that revolves around the use of machine that mimics human cognitive system such as learning, pattern recognition, problem solving and decision making (Dobrev, 2012).

3.2 Machine Learning (ML)

ML is a subset of AI and computer science that allows computers to comprehend information from past experience. ML can also be defined as a branch of AI that focuses on the use of algorithms and data to mimic human behavior such as learning and gradually improving over time. Machine learning is a branch under AI that utilize statistical approach to give computers and machine the ability to learn from data without being explicitly programmed. AI models require data to function effectively in the same manner where vehicles require fuels to function. Computational approaches are used for ML algorithms to specifically learn information from input, without using a fixed model equation. ML is one of the basic drivers of the growing field of data science, automation and smart systems. The concepts of ML have been applied in the form of algorithms or statistical method to make predictions, classification and uncover patterns in data. Thus, the use of large amount of data is crucial for boosting the efficiency and accuracy of ML-models (Bottou, 2014; El-Naqa and Murphy, 2015). The classification of ML techniques is presented in Figure 3.

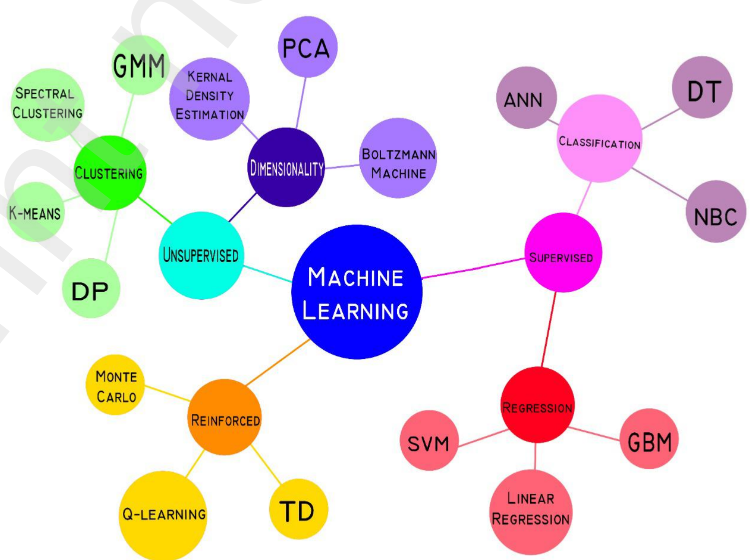

Figure 3. Classification of ML Techniques

3.2.1 Supervised Learning

Supervised Learning is a ML paradigm for acquiring the input-output relationship information of a system based on a given set of paired input-output training samples. It is called supervised because we know the correct output and the algorithm iteratively makes predictions on the training data and corrected later through gradient descent. The training will stop when the algorithm achieves the acceptable level of performance we ought to. Two of the main methods used in supervised learning are Regression and Classification. Example of Regression algorithms include Gradient Boosting Machine (GBM), Linear Regression and Support Vector Machines (SVM), whereas, example of classification techniques include Deep learning architectures such as Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNNs), Decision Trees (DT) and Naïve Bayes Classifiers (NBC) (Bottou, 2014; Jiang et al., 2020; Xu et al., 2021).

Deep learning

Deep learning is a subfield of ML which is inspired by how human brain's function due to connections or synopsis of nerve cells or neurons. Model learn as a result of data connection between neurons in the network. A simple neural network is termed as perceptron which take input as data set and produced an output as classification category or prediction outcome. Deep learning neural networks are made of multiple perceptron's with an Input Layer (IL), and many hidden layers (HL) before Output Layer (OL) (Abiyev et al 2018). An example of deep learning includes artificial neural networks (ANN) and Convolutional Neural Networks (CNNs). ANN consists of a network of strongly integrated processing elements (known as neurons), which work together to address a particular problem. CNN is a class of ANN with multi-layer perceptron which are fully connected network in which each neuron from one layer is connected to all neurons in the next layer. CNN are termed as networks that utilize series of mathematical operations knows as "Convolution" (Helwan & Abiyev 2016).

Linear Regression (LR)

The concept of Linear regression is popular as a result of its application in statistics. Linear regression is use in several disciplines such as marketing such as prediction of profits and prices of commodities, prediction of weather and climate, healthcare (progression and spread of diseases, data analytics of medical records etc.) LR is an approach use to model target values using independent predictors. LR is crucial for prediction and evaluating the causes and effect correlation between variables. Liner regression and Logistic regression are the two most common type of regression. The differences between regression types revolve around the number of independent variables and type of connection between dependent and independent variables. The concept where there is only one independent variable and introducing dependent variable resulted in linear relationship between the independent (y) and dependent (X) variable is known as simple LR (Maulud and Abdulazeez, 2020; Jiang et al., 2020). The formula for LR take the form of:

$$Y = a + bX$$

and expanded to

$$Yi = f(Xi + \beta) + ei$$

Where,

Yi = dependent variable

f = function

Xi = independent variable

beta = unknown parameters

ei = error terms

Support Vector Machine (SVM)

SVM is a simple type of supervised machine learning which is used for both classification and regression. The main objective of SVM is to locate a hyperplane in an N-dimensional space which clearly classifies the data points. Despite the fact that SVM can be used for both regression, outlier detection and classification, most researchers applied SVM for binary and multi-class classification which makes one of the most popular supervised machine learning techniques (Bhavsai and Ganatra, 2012).

Segregating classes using hyperplane by maximizing the distance between nearest points known as Margin is the core mechanism behind SVM classifiers. The phrase support vector in SVM denoted as the application of classes of training points in the decision function. SVM algorithms is designed using a technique known as kernel trick which is a function that transform high dimensional space from low dimensional space inputs (Abe, 2005). SVM is crucial in separating complex or sparse data into simple groups or categories according to labels define by researchers. Unlike the use of SoftMax as final fully layer in majority of deep learning algorithms for classification based on probability, SVM classify inputs using five cross validations. Some of the advantages of SVM over other ML models include low computation, higher speed and better performance with small amount of data unlike DNNs that require substantial amount of dataset for higher accuracy (Gupta et al., 2014).

Decision Tree (DT)

The application of tree-based algorithms has shown several advantages over Linear Regression (LR) due to their stability, high accuracy and ease of interpretation. LR models have shown to map out linear relationships efficiently. However, tree-based algorithms are excellent in mapping non-linear relationships between variables and thus they are used for both classification and regression. DT is a subtype of supervised ML that is employ for classification of inputs based on predefined target variables. In another words, DT is a decision support mechanism that utilizes a tree-like network of outcomes containing chance events, costs and utility (Thakur et al., 2010).

DT models can be used for both binary and multi-class classifications using “splitter” approach. As a result, it has gained rising interests because of its high-caliber in terms of computational capability, uncertainty manageability, and observability (Liu et al., 2013). DT model is inputted with unsorted, complex or sparse inputs known as “Root Node” which can be segregated or split using splitter to create a class sets of outputs. However, not all inputs can be splits into groups (which are termed as terminal node or leaf). DT offer data analysts with several advantages such as easy to understand and interpret, require less data processing steps, and can be used for both categorical and numerical data (i.e., no data constraints), while overfitting is one of the most common disadvantages of DT models (Hoens et al., 2012; Shao et al., 2013).

Naïves Bayes Classifiers (NBC)

NBC is a subtype of supervised ML which employ Bayes theorem of probability to predict class of unlabeled datasets. This machine assumes features of a data point as being totally independent of one another and that's why it's called Naives Bayes Classifiers. The classifier uses in Naïve Bayes take into accounts "that the presence of specific trait in a group or set has no relation with the presence of any other traits". They use the probabilities of defined circumstances being true (input) to make predictions for new data points (Xue et al., 2021). Application of NBC follow several steps which include data conversion (into frequency table), finding probabilities or creating likelihood table and finally the use of Naïve Bayes equation to calculate class problem as shown in the equation below:

$$P\left({}^{C}/_{X}\right) = \frac{P({}^{x}/_{C})\,P(C)}{P(x)}$$

Where P(c|x) is the posterior probability of class (c, target) given predictor (x, attributes).

P(c) is the prior probability of class.

P(x|c) is the likelihood which is the probability of predictor given class.

P(x) is the prior probability of predictor.

One of the advantages of NBC is it is very easy to build, can be apply for large number of datasets and can be used for both binary and multi-class classification. Some of the advantage of this technique is that it performs better using categorical dataset compared to numerical dataset, assumption of independent predictors or it takes time and assumes data point features are independent and bad estimator which ends up slightly less accurate compared to other classifiers (Jindal et al., 2020).

Gradient Boosting Machine (GBM)

This technique employs logic in which the subsequent predictors learn from the mistakes of the previous predictors. Therefore, the observations have an unequal probability of appearing in subsequent models and ones with the highest error appear most. As a result, the examinations are not built on the bootstrap process, but mainly focused on the error. In other words, its ensemble tends to improve accuracy with some small risk of less coverage. Some of its benefits include providing highly predictive accuracy which works great with categorical and numerical values (Babar et al., 2020). On the other hand, it's harder to tune than other models as it got many hyperparameters so it can easily overfit. It optimizes different loss functions and provides several hyperparameter tuning options that makes it easier for the function to fit and so, flexible. It lacks interpretability compared to linear classifiers which means, it doesn't have a straightforward way to study how variables interact and contribute to the final prediction. It is not that fast in training nor scoring but it at least doesn't require imputations when handling missing data (Babar et al., 2020).

K-Nearest Neighbor (KNN)

The concept of "similar features flock together" is the basis of KNN algorithms. Thus, KNN models are associated with "proximity" due to similarity concepts or closeness. Even though KNN can be used for regression, however, it is widely used for classification problems. The working principle of KNN revolve around storage of dataset during training session and the subsequent addition of new set of data which result in classification of the new input dataset into categories according to the store dataset. KNN is very effective in classifying similar datasets into categories using nearest data point (Taunk et al., 2019; Cunningham and Delany, 2021)

The steps involve for application of KNN include selection of K numbers of the neighbors, estimation of Euclidean distance of the neighbors, calculation of data point of each category and assigning of new data points. One of the disadvantages of KNN algorithms is that it is a "lazy learner" as it does not learn immediately from training dataset but store them. It is also non-parametric technique which does not make any assumption on primary datasets (Cunningham and Delany, 2021).

3.3 Unsupervised Learning

Unsupervised ML is a type of ML which use unlabeled inputs. Unsupervised ML models learn functions by identifying patterns in input data and cluster them together in the form of groups or classes. This subtype of ML gives more insight into the type of inputs which makes it crucial for classifying unsorted, sparse and complex data. It is applicable generally in clustering and dimensionality approaches. Clustering techniques can vary to K-means, Principal Component Analysis (PCA), Spectral clustering and Dirichlet process, and Density Estimation are like Boltzmann Machine, Kernel density estimation and Gaussian Mixtures (Usama et al., 2019).

K-means

The k-means clustering algorithm aims to allocate an identified unspecified data set into a defined number of clusters. K-means are simple to execute and calibrated to large sets of data as well as easily adapted to different examples in which clusters of distinct shapes and dimensions are generalized. However, the "k" has to be chosen manually where it depends on the initial values. For instance, it is a big problem when using the Euclidean distance because it calibrates with a number of dimensions. So, whenever the number of dimensions lean to infinity, the distance between any two points in the dataset merge. It has trouble clustering data when using different shapes and sizes, so it should be generalized (Ebrahimpour et al., 2012).

Principal Component Analysis (PCA)

PCA is a long-established feature of extraction and data characterization technique significantly used for statistics primarily for dimensional reduction, extracting and representing data. Its main role is to reduce the dimensions of a data set consisting of many variables correlated with each other, while maintaining the variation at hand in the dataset. Its objective was to orthogonally project data points onto an L dimensional lateral subspace (Mahdavinejad et al., 2018). In order to capture or ignore the easiest invariance, a greater number of functionalities is required for calculation and performance reasons. PCA concerning covariance tends to lack information and to hide certain data structure and interactions. This makes the covariance matrix difficult to assess properly, but that doesn't alter the fact that the original data is preserved with extraordinary performance (Karimizadeh et al., 2020).

Spectral clustering

Spectral clustering is a technique that operates in graph theory, it is used to recognize sets of nodes in a graph based on the edges linking them, they are mainly used for exploratory data analysis. The purpose is to allocate unlabeled data to groups, where similar data points get exploited to the same group. Some of its advantages is that they reduce the computation lay out efficiently, works for any choice of weights, produces consistently high-quality results, validates and improve the phase labels in the utility model and shows potential in the detection of other types of errors in the topology of the model. On the other hand, if the resolution of the image is high, it can lead to an intensely large adjacent matrix. It is not effectual with noisy, sparse data, and the prediction can be made only for one cluster model at a time (Blakely et al., 2019; Ahmadi et al., 2021).

Boltzmann Machine

A Boltzmann Machine is a bidirectional network of aligned neuron-like units linked together to assemble debatable decisions about whether to be on or off. It generates data from the training process (without expecting input data) and feed it to the machine as input to help the system regulate its weight. The learning process is done from the input where it scans the possible connections between the parameters and how they affect each other (Zhang et al., 2018B)

Gaussian-Mixture Model (GMM)

GMMs are a parametric probability density function for representing normally distributed sum of Gaussian component densities. Their architecture works by limiting the spectrum of normal data to be collected through the clustering and learning of upper and lower bounds or distances to each centre of each cluster. GMM can be very useful for identifying cases where there is limited number of sample class of interest and substantial number of samples of other classes. Its covariance structure allows mixed membership of points to clusters which makes it very flexible. One of GMM's drawbacks include having a lot of parameters to fit that usually require loads of data and multiple iterations to get quality results (Yang et al., 2016).

3.4 Reinforcement Learning

RL is the training of ML models to assemble a series of decisions where an agent learns from a bilateral domain by trial and error using judgement from its attained experience and actions. RL uses rewards and punishments as alerts for the desired or undesired behavior. It is used to quantify a behavioural approach, a policy optimizing a criterion of fulfilment. As such, a long-term amount of reward comes from engaging with a certain setting through discovery and error. Its goal is to find a suitable action model that would boost the total cumulative reward of the agent. It is divided into two main types: Policy iteration and Value iteration based. Policy-iteration based are like Monte-Carlo simulation and Temporal Difference (TD) learning, and value-iteration based is like Q-learning (Fenjiro and Benbrahim, 2018; Nian et al., 2020).

Monte-Carlo simulation (MC)

The Monte-Carlo method manifests all the feasible outcomes of your choices and estimate the risk effect, granting for a finer decision making when it's unpredictable. It carries out risk analysis by constructing models of potential results by switching a variety of values using probability distribution for any factor that has ingrained uncertainty. After calculating the results multiple number of times using a distinct set of irregular values from the probability functions. The MC simulation could involve a great deal of recalculations before it concludes (Raychaudhuri, 2008).

Temporal Difference (TD)

TD is an agent learning to predict the expected value of an inconsistent variable occurring at the end of a sequence of states. It pursues the unsupervised learning as it learns from an environment through episodes with no prior knowledge of the environment in this approach. It considers learning from trial and error and improves according to that. The crucial part is to learn how to set the rewards, the initial estimation and update it based on the exploration efforts appropriately. The design acquires knowledge from past events using qualified traces and so tend to assemble better predictions. It is also used to predict the optimal approach for the cost function. However, training the model to estimate the Q-function from the current reward is done by the analyst but the estimation for the future reward is done by the model itself. That's what makes it unstable as the targets are based on the model itself. Moreover, TD is biased to maximizing the outcomes and that's where the policy-iteration kicks in. Q-values are most probably the perfect targets but it's unknown and the model should be trained to estimate them instead (Esmalifalak et al., 2014).

Q-learning

Q-learning is an off-policy algorithm that takes the best steps in its newest state. It focuses on the quality and how proficient a given action is in acquiring feature rewards. It is considered off-policy because the function seeks to learn the value of the ideal policy independent to the agent's actions to maximize the total reward. This framework combines the advantages of unified and decentralized architectures to achieve reliable decision. This established structure allows he agent to take precise decisions in order to defend themselves against shortcomings in a timely manner without the necessary rewards. Throughout the process of having to learn a policy and the overall approach to maximize the reward, the degree of potential error will be magnifying. In addition to that, it uses the TD and so the drawback of having the model slightly unstable also applies (Ye et al., 2011).

4. Internet of Things (IoT)

The concept of Internet of things was coined in 1999 by a member of Radio Frequency Identification (RFID) development community. IoT is born out of the integration of other technologies in the field of communications which include Information and Communication Technology (ICT), data analysis and artificial intelligence (Wortmann and Flüchter, 2015). The other family members of IoT include Industrial Internet of Things (IIoT), Internet of nano Things (IoNT), Internet of Medical Things (IoMT) or Internet of Things in Healthcare (IoTH). IoT is a broad term that encompasses billions of physical objects or devices that are capable of collecting and sharing data with other devices, system or living things using the internet (Al-Turjman and Al-Turjman, 2018; Aman et al., 2020). Despite the fact that the concept of IoT has been in existence almost 3 decades ago, however, it wasn't until 2011 that it become prominent and enlisted among the emerging technologies. This owes to the technological advancement in different fields of science and engineering such as hardware which include advancement in sensors and smart devices and software as well as advances in artificial intelligence and cloud computing (Rose et al., 2015). IoT devices are designed with Unique Identifier which allow them to exchange data without human intervention. In other words, IoT is a pandora box that is open by advances in ICT, electronic and mechanical or mechatronics engineering. The Unzipping of this technology has made it possible for the interaction between digital and physical world (Mora et al., 2018).

The concept of IoT revolves around the exchange of information or data between people and devices equipped with sensors and monitors using wireless connection. IoT is regarded as network of physical objects which encompasses the wireless connectivity of devices of all sizes and types such as computers, smart phones, vehicles, cameras, toys, home appliances, buildings, industrial devices and systems as well as people and animals (Khodadadi et al., 2016). IoT involve connectivity, communicating and sharing of information according to specified protocols for the purpose of accomplishing smart reorganizations, personal real-time monitoring, tracing, positioning, online upgrade, online monitoring, process control and safety etc. The basic principle behind IoT revolve around the use of smart devices which are embedded with sensors, processors and communication that enable them to acquire, store and transfer data using an IoT gateway or stored in cloud. IoT is not only limited to exchange of data with people and device through a network but also exchange of data from one device to another (Li and Chen, 2012).

4.1 Component of IoT

The three main components of IoT are the devices, software and the internet or network.

IoT-based Devices

IoT-based devices are mainly hardware devices designed or embedded with sensors and monitors such as gadgets, appliances, industrial machines, medical equipment which are capable of collecting and exchange data over the internet. These devices are also integrated with CPU, firmware, network adapter These embedded sensors enable the device to sense physical changes and record, store or transmit the information to a server or other connected devices (Rose et al., 2015).

Software

The architecture of IoT-based devices requires the use of software which interact with hardware board using the internet. For each device, one input output pin of hardware board is connected with every single relay module which act as a switch for the devices. The hardware board is then assigned with a static IP to allow access or execute it stored scripts with the aid of software applications. Thus, the main function of Software in IoT devices revolve around configuration and management (Shah and Mahmood, 2020).

Internet

Internet is a broad term use to describe system architectures that connect devices together through a network. Thus, it is termed as “Network of Network”. The internet provides a means by which people communicate with each other through an online and social media platform which include email, Facebook, WhatsApp, audio, video calls and online conference call or store information in a drive or cloud (Gowda et al., 2020). The internet has provided a means of transaction and businesses around the world. Internet is not only limited to wireless connections but also physical objects such as cables. Thus, internet is regarded as global network of physical cables which include fiber optic cables, telephone cables, TV cables etc. (Leiner et al., 2009). With these cables or wireless connections using Wi-Fi, computer and other smart devices can access the internet through an internet provider network. Thus, internet provide a means where devices can connect with each other, store and transmit data which make internet the backbone of IoT (Gowda et al., 2020).

4.2 Significance of IoT

IoT is transforming almost every sector as a result of internet, cloud computing (CC), Big Data (BD), Data analytics (DA) and hardware such as computers, smart mobile phones and other electronic devices. Internet of thing IOT is literally the inter connectivity between internet and thing which can be a person, an animal, a device such as implants, biochips, automobile or any other biological or natural and manmade object that can be assigned an internet protocol address in order to transmit data through a network. Currently, several companies and industries from different disciplines are using IoT to improve production and services. Integrating IoT has shown to reduce labor, cut cost or minimize losses, reduce waste and improve service delivery (Lombardi et al., 2021).

4.3 Classification of IoT

As a result of vast number of IoT devices in existence, classifying them is challenging due to numerous applications in different fields and disciplines. One of the most popular classifications of IoT devices are based on their application such as in the industries also known as Industrial Internet of Things (IIoT), in medicine or healthcare also known as Internet of Medical Things (IoMT), in the military also known as Internet of Military Things etc. other classification of IoT include consumer-based IoTs, commercial based IoTs, Infrastructural based IoTs etc. (Rose et al., 2015).

4.4 Application of IoT

The 21st century is witnessing growing applications of IoT in wide range of human activity. This trend is forecasted to increase exponentially in the next few years from billion USD dollar industries to trillion USD dollar industries. IoT has found its applications in several domains which include smart healthcare, energy, security and safety, agriculture, construction and buildings, cities and environment (Serpanos and Wolf, 2018; Lombardi et al., 2021) as shown in Figure 4. Some of the current's applications of IoT include:

1. Home security: IoT-based devices in the form of sensors, monitors, cameras and motion detectors have been developed to help make home secure (Sivaraman et al., 2018)

2. Monitoring of vital signs: The growing field of wearable devices integrated with IoT is transforming real-time monitoring of vital signs both at home and in the healthcare settings. Several IoT devices have been developed to monitor body's temperature, heart rate, glucose level, pressure, steps and calories burn and transmit the data to end users such as physicians or cloud storage (Pradhan et al., 2021).

3. Transportation: The high need and demand for self-driven cars has led scientist to adopt several technologies which include AI through machine learning such as image classification and reinforcement learning. However, IoT systems can also be used for inter and intra vehicular communications, GPS and location tracking, smart parking, smart traffic control etc. (Zantalis et al., 2019).

4. Industrial Internet of things IIoT: Several industrial processes are now automated as a result of sensors capable of wireless connection and transmission. The dream of smart manufacturing is edging closer with every passing year. The increase demand of smart industry and safer industrial environment has led so many organizations to promote the integration of IoT in the industry in order to increase productivity, flexibility while reducing the cost. Some of these strategies and campaigns includes the industries 4.0 strategy, the European initiative for the Factories of the Future (FoF), Industrial Internet (GE17) and the effort for smart factories (Serpanos and Wolf, 2018). Recently scientists developed platform that allow machine to machine communication. The application of Wireless Sensor Networks (WSNs) has shown great promise in promoting IIoT in terms of enhancing efficiency and productivity of both current and prospective manufacturing industries (Nkomo et al., 2018).

5. Military Internet of Things: The exponential technological advancement in the field of ICT and related technologies such as software, network and mechatronics have led to the development of several new military information technologies which include information security technology, sense detecting technology, command decision-making technology, information fusion technology etc. Collection of these technologies have shown to aid the military on information processing, system design and technology innovations centered around IoT. The military internet of things (MIOT) is driven by the use of sensors and other devices equipped with information system technologies which enable them to capture physical attributes and provide state information of enemies, their war tools and materials using various sensing technologies (Yushi et al., 2012; Iyer and Patil, 2018).

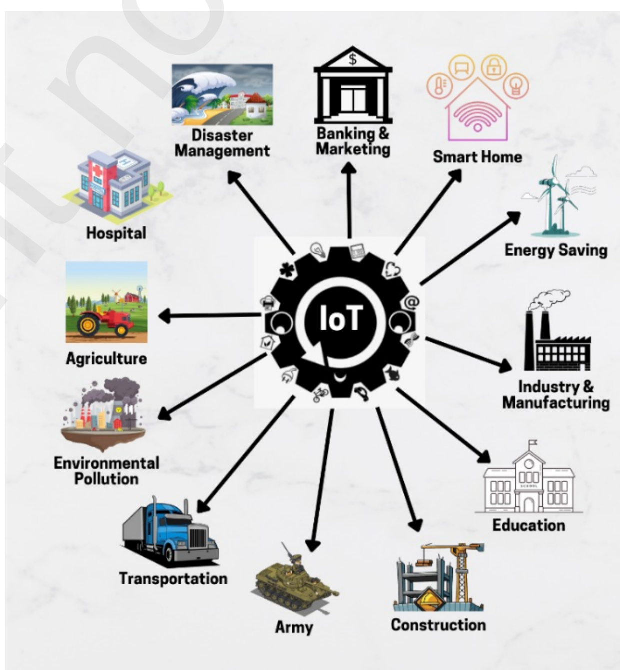

Figure 4. Application of IoT

5. Integration of Smart Technologies in Construction sector

Buildings are among the basic and fundamental unit of human beings as it offers shelter against environmental factors and intrusion from animals. Throughout history, humans have transformed buildings from construction using old-age or primitive tools using mud and clay to concrete, wood, steel and glass buildings constructed using advanced and sophisticated devices such as BIM and 3D printing technology. The second phase of transformation in construction sector is associated with the invention of electricity which powered homes with light and electrical devices such as television (TV), microwave, oven, fridge, washing machine etc. (Apanaviciene et al., 2020; Silverio-Fernández et al., 2021).

Developing smart homes has become a trending topic in the last 2 decades as it offers better quality of living through the integration of technology and services by harnessing hardware or electronic devices and internet. Smart homes provide ease and convenience to users and their daily activities through automation. Smart homes utilize several wireless connection technologies which allow devices communicate with each other through the internet, cable broadband, Bluetooth etc. as shown in Figure 5. Building smart home requires the placement of devices and networks around the house such as living room, bedroom, kitchen, bathroom, storage, garage etc. Smart home provides users with several features and applications which include security, energy management, comfortable living as well as added benefits for disabled people. (Lakshmi et al., 2019). Moreover, smart homes are integral to realizing smart cities (Mandula, 2015).

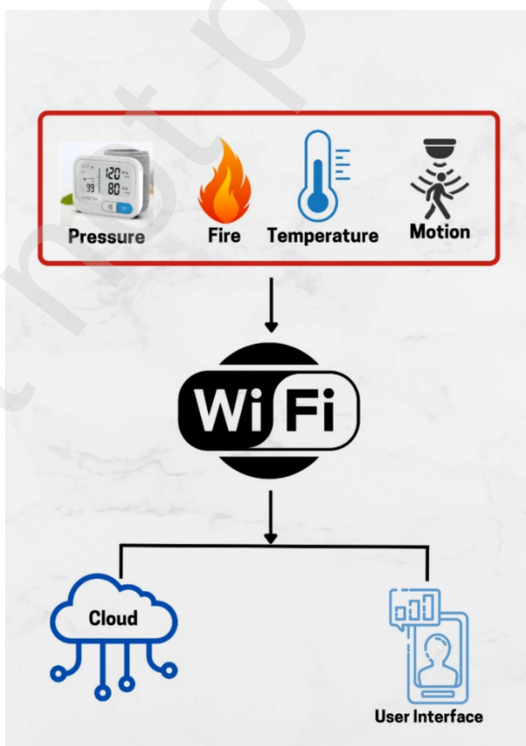

Figure 5. Application of IoT in Smart Homes

Among many IoT applications, smart homes play an important role in realizing smart cities. The idea behind smart buildings originated as a result of increase automated innovations in construction and maintenance of buildings. Smart homes offer several advantages over traditional or conventional homes in such a way it can be remotely operated and controlled which improved comfortability, convenience, energy-saving and minimize cost. The adoption of IoT, AI, Cloud Computing (CC)), Big Data (BD), Sensor Technologies, Data analytics in buildings give rise to a concept known as Intelligent Buildings (IB) which is prerequisite and driver of smart homes (Hui et al., 2017; Jia et al., 2019)

Building smart homes required the use of automated technologies which can provide several advantages over traditional approaches and various application. Starting from construction, the use of 3D printing has shown to offer several advantages which include efficiency, speed or time saving, affordability, resource and waste management etc. Next is the interior and decoration of smart homes which require the use of IoT-based devices that can be used to connect different devices together (Stojkoska and Trivodaliev, 2017).

5.1 Construction of buildings and components using 3D Printing Technology

3D Printing in Construction

The first reported engineering of 3D printing is dated back to the 1986 and subsequently, the technology has been adopted in other fields such as healthcare, architecture and other designs. 3DP technology has attracted interest from researchers and firms in the construction sector (Tay et al., 2017). Lim et al., 2012 developed a full-scale concrete printing of walls and frontage which are limited in size (i.e., 5.4x4.4x5.4m). However, the first full-scale printing of houses was developed in 2014 by a Chinese company known as Winsun who developed several printed houses within one day (Wu et al., 2016).

In construction industry, 3D printing technology was firstly introduced for a quick and precise creation of prototype parts. However, the technology was improved due to integration of automation which expands it viable application to onsite construction of buildings. 3D printing was also adopted by architects to design sale models prior to introduction of Building Information Modelling (BIM) (Ma et al., 2018). Since the first inception or an attempt to incorporate 3D technology into construction in 2004, construction engineers have deployed 3D technology for building construction structures and full-scale construction.

The transformation of small-scale structures to full-scale structures was made possible due to the developments of large-scale 3D printers which led to the construction of offices, houses, shelters, bridges, pavilions, etc. (Alhumayani et al., 2020). These buildings show the potential of the technology and the prospect of employing the technology for construction of large-scale, high and tall buildings in small time frame, limited resource, less waste and construction error (Al-Rashid et al., 2020; Hossain et al., 2019).

Apart from building structures using 3DP, the technology has also been deployed in other construction such as military bunkers, printing of pedestrian bridges, reproduction of historical buildings, in situ repair work which are not accessible or difficult for humans, printing of structural and non-structural elements with complex geometries, quick construction of disaster relief shelter or refugee camps, printing of metal frames, printing molds for load bearing components, etc. (Wu et al., 2016; Zhang et al., 2019; Delgado et al., 2019).

Scalability is one of the challenges related to the use of 3D printers where the size of the design is impelled by the chamber volume of the printers. In order to address this issue, scientists turn to printing smaller pieces off-site which can then be assembled on-site. However, these generates extra work such as transportation, assembling which create potential weaknesses. Thus, Zhang et al., 2018A addressed this issue by proposing the use of multiple robot printers in multi-agent environment to print separate portion of large print structures. These printers have shown to be capable of collision avoidance, localization and effective and organized printing. Keating et al., 2017 who are group of scientists from Media Lab at the Massachusetts Institute of Technology developed an automated construction system known as Digital Construction Platform (DCP) which has the ability for customized on-site printing of architectural-scale structures. The design of the system revolves around a compound arm system which consists of both electric and hydraulic robotic arms and the use of AM approach for constructing insulated frameworks cast concrete structures using two-part spray polyurethane foams.

Currently, the largest building printed by 3DP is the 9.5m high and 640 square meter flow space office building in Dubai which was constructed by Apis Cor in 2016. After the completion of the office building, the constructors claimed that the construction generated approximately 60% less waste compare to conventional approach, utilize 50% less human resource and was completed within 14 days (Bravo, 2021). Apart from printing structures such as the office walls, it took the company extra 2 months to fix ceilings, fittings and electronics (Siddika et al., 2020; Hossain et al., 2020).

The office constructed by Apis Cor is the current largest building in terms of space, while the five-story apartment constructed by Winsun is the tallest (highest) 3D printed building as shown in **Figure 6.** Unlike the Apis Cor, the Winsun Company printed walls and other structural components off site and transport the structure on site for assembling. However, conventional approach was employed for fixing doors, windows and other finishing works. After the completion of the building, the constructors claimed that the construction operations saved construction time by approximately 70%, construction waste by 60% and labour cost by almost 80% (Hossain et al., 2020).

Figure 6. 3D printed building in Dubai by Apis Cor: a and b) during printing and C) finished in its environment

Another construction printed using the 3D printing also located in China was constructed by HuaShang which is a two-story building. Unlike the one developed by Winsun off site and assembled on site, this one was printed entirely on site which save time (i.e., transportation and assembling times). It took the constructors almost 45 days to complete the building from printing to plumbing and other fittings. This demonstrates the speed of using 3DP compare to conventional building approach which would take around 7 months (Siddika et al., 2020; Hossain et al., 2020).

3D printing has also been applied for other types of construction apart from buildings for daily use such as lunar habitat, drilling unit for ocean mining in frozen lands (such as Antarctic and arctic region) and emergency housing for refugees and those affected by disasters such as earthquakes and floods.

A 3D printer known as INNOprint was developed by the university of Nantes which is used to construct emergency housing in just 30 minutes (Pan et al., 2021). Zhang et al., 2021 proposed the use of a cable-driven printer for construction of lunar architectures. The evaluation of the printers exhibits several advantages such as small weight, simple structure, excellent reconfiguration features and large forming space. Unlike the use of earthly materials for construction of lunar bases, scientists proposed an efficient approach for lunar construction known as the "Lunar Soil 3D Printing". Some of these techniques include microwave sinter by the Institute of Geochemistry, Chinese Academy of Sciences, microwave sintering and contour crafting by NASA, solar sinter by Markus Kayser etc. (Ulubeyli, 2022).

The timeframe for 3D technology is summarized in Table 3.

Table 3. History of application of 3DP technology in construction

Year	Contribution
2004	Behrokh Khoshnevis of the University of South Carolina accredited for the first attempt to build printed walls
2014	Construction of full canal house using 3D printing technology in Amsterdam, Netherlands.
2015	NASA launched the '3D Printed Habitat Challenge for printing building home prototypes in space
2016	Construction of office of the future a 2,700-square foot building in Dubai UAE in less than 20 days
2016	Construction of 4,300-square-foot home by HuaShang Tengda, a Chinese architectural firm in one and half months
2017	Construction of a house by Apis Cor a Russian company in just 24 hours using 3D printing technology
2020	Construction of 380 square meters house by Peri group a German construction
2021	Construction of lunar architecture by Institute of Geochemistry, Chinese Academy of Sciences and NASA

5.2 Application of ML in Construction

The application of AI has the potential to help construction experts realize value, increase efficiency, productivity through various stages of construction project such as design by architects, business modeling, financing, procurement, construction process and operations and asset management. Moreover, the application of AI in construction can help address several challenges which include resource management, cost, labor shortage, waste management and safety. The advancement in AI and its subfield such as ML and DL as well as analytics and big data are transforming construction sector (Xu et al., 2021).

The potential of ML in construction is unlimited. Several algorithms have been developed to assist project and construction managers on critical issues that require their attention. Several applications of ML are tailored toward prediction and classification using ANNs and CNNs. Currently, Deep NNs are used in predicting cost overruns by imputing data related to factors such as project size, project type, resources available, competence level of team and mangers. These types of models can also be used to predict realistic timeline for completion of construction using store data of previous projects (Bassier et al., 2017; Xu et al., 2021).

Coskuner et al., 2021 applied multi-layer perceptron for the prediction of construction, domestic and commercial waste. The model is feed with several variables which reflect the effect of economic, social, geographical, demographic and touristic factors for the prediction of yearly generation rates of different type of waste. In order to provide an efficient system for evaluating vulnerability of existing buildings, Ruggieri et al., 2021 proposed a machine learning model named as VULnerability Analysis using MAchine-learning (VULMA). The proposed algorithm is fed with photographs of existing buildings in Puglia, Southern Italy. The proposed model exhibits high performance in comparison with manual computations conducted by the researchers.

Energy saving in the construction industry has been a major challenge for years. Thus, the study conducted by Mateo et al., 2013 proposed the use of different machine learning models such as Robust multiple linear regression, non-linear autoregressive exogenous multilayer perceptron, autoregressive model, extreme learning machine, multilayer perceptron, clustering for prediction of temperature in each room of a building using data obtained by stimulating building in TeKton. Among the models utilized, the non-linear Autoregressive Exogenous multilayer perceptron achieved the best performance with mean error approximately 0.1 degrees centigrade. Similarly, Olu-Ajayi et al., 2022 applied several machine learning models which include SVM, ANN, DNN, KNN, DT, Gradient Boosting GD, Random Forest RF, Linear Regression and stacking for predicting annual building energy consumption. Among the models applied on large dataset of residential building, DNN has shown to achieved the best performance with 0.92 MAE Mean Absolute Error 1.34 MSE Mean Squared error, 0.95 R squared and 1.16 RMSE Root mean square error.

Prediction of cost of construction is crucial for efficient management of projects. The study proposed by Sanni-Anibire et al., 2021 explored this gap by predicting preliminary cost of tall building projects using different machine learning models which include ANN, SVM, Multiclassifier system, K-nearest Neighbors (KNN) and other single and hybrid models. The result indicated that the combination of Multi classifier system and KNN achieved the best performance with 80.95% mean absolute percentage error, 6.09 root mean square and 0.81 correlation coefficient. The study conducted by Ngo (2019) proposed the use of ML approach to predict cooling load of buildings. The developed models which include SVM, ANNs, Classification and Regression Tree, and linear regression models were fed with dataset obtained from 234 buildings and the resulting performance is compared with the ones from physics-based. The comparison analysis has shown that the use of ML agrees with physics-based and the use of ensemble achieved the best result with 158.77KW RMSE, 0.99 R, 6.17% MAPE and 112.07KW MAE.

The use of machine learning for automated classification of heritage buildings is proposed by Bassier et al., 2017. The authors employed SVM for classification of objects and buildings such as churches, offices, houses, industrial buildings acquired using terrestrial laser scanning technique. The model was successful in terms of extracting structural components such as roofs, ceilings, floors, windows. The performance evaluation of the model resulted in 81%average accuracy, 80% and 82% average recall and precision. As a result of the significance of occupancy information in building facility design, operation and energy management. Wang et al., 2018 adopted 3 machine which include ANN, KNN and SVM using 3 different datasets, Fused data, Wi-Fi data and environmental data. The performance of the models has shown that ANN achieved the best result with 3.0 average RMSE, 2.3 average MEA and 32.2% average MAPE.

5.3 Application of IoT in construction and building

One of the sectors that attracted several applications of iot is the construction sector. Several houses are equipped with sensors such as temperature, gas leakage, light sensors, camera etc which is term as smart houses. The use of wireless sensor is transforming smart homes. They play crucial role in sensing environmental parameters which include humidity, temperature, light air quality (such as dust levels and CO_2). Electronic sensors are becoming hot topic nowadays especially in smart homes. They are used for several applications such as shading, controlling light and room climate. In order to monitor and save energy, scientists integrated IoT systems in homes and other buildings such as hotels, halls, offices etc. (Alaa et al., 2017; Anthi et al., 2019).

Home automation can be achieved by placing sensors at different locations around the building. The raw data acquired using these devices can be process by transmitted through wireless connection or other data sharing or transmission platforms to a processor. The processed data can be further translated and transmitted back to the device or another device to be controlled automatically or to a user interference (Lamine and Abid, 2014). Several construction and architectural firms such as Intel and IBM have launched smart home buildings to the global market, demonstrating their advantage over conventional buildings. In order to understand how IoT is shaping smart buildings, there is need to review and understanding existing studies attempted to integrate IoT into the industry.

Al-Kuwari et al., 2018 developed smart home automation system which is designed by integrating IoT system to allow monitoring and sensing of variables. The device architecture consists of EMON CMS system which is employ for collecting and controlling of home appliances and devices and the use of microcontroller for both real-time data processing and sensing. Mandula et al., 2015 proposed an IoT-based smart home automation system designed using a micro-controller-based Arduino board and Android mobile app. The authors developed two prototypes which include home automation system that use ethernet in an outdoor environment. This type of prototype utilized Ethernet module which is used for connecting Arduino board from any part of the world using IP address and Port number. The second prototype use Bluetooth in an indoor environment by establishing connection between smart phone devices and Arduino which is an open-source system that can be utilize for prototyping any software and hardware and can receive data from sensor or input from keyboard and simultaneously control several electrical appliances connected to output peripherals.

5.4 Challenges

Integration of technologies for the development of smart homes is facing both direct and indirect challenges such as adoption of automation in construction sector, the need of large-scale data for AI and security and privacy challenges associated with IoT devices.

Adoption of automation in construction industry

Adoption of innovation and automation in the construction sector is relatively slow and shifting away from conventional construction to automated construction has been facing difficulties due to high cost of machine, equipment and tools, the requirement of professionals or expert that can operate the tools, low technological readiness, lack of organizational support and awareness campaign, as well as lack of policy and regulatory considerations. However, despite the significant benefit of 3D printing in construction and its potential or advantages such as speed, affordability, reducing construction errors, waste reduction, labour reduction, sustainability etc. One of the major or leading factor that limit the currents adoption of 3D printing in many countries is that the construction sector is one of the direct sources of employment for millions of people (Hossain et al., 2020; Regona et al., 2022).

Privacy and Safety

The landscape of IoT-based devices is gradually growing day by day and becoming more diverse in terms of production and applications. As a result, these devices are vulnerable to wide range of security and breach of privacy. Despite the fact that most of IoT devices require authentication as a way to safeguard the system, however, authentication process has shown to only safeguards against few threats or attacks. The application of IoT in smart building is greatly hindered by the issue of user privacy. The omnipresent connectivity of IoT-based devices to the internet and cloud system plays vital role in magnifying privacy concerns from users. Protecting people personal lives is crucial for the growing applications of IoT as well as developing confidence and trust of users (Al-Turjman et al., 2022).

Lack of Sufficient Amount of Data

Despite the growing of big data and other technologies such as cloud computing and data analytics, the application of ML in construction is still hindered by the lack of required amount of data. Development of automated and smart systems require the application of reinforcement ML which allow machine to learn by training and trial and error. The use of deep learning such as ANNs and CNNS require vast amount of data for higher performance. However, the use of transfer learning has shown addressed some of the challenges related to training using small amount of dataset and tediousness of developing model from scratch (Zhang et al., 2021B; Regona et al., 2021)

6. Conclusion

Technological advancement in the field of science has led to several innovations. The field of civil engineering is undergoing transformation due to integration of machines and artificial intelligence. The major challenges facing construction of houses, bridges and other buildings revolves around the desperate need to cut construction time, the use of suitable efficient, stronger, construction material, and the need to construct buildings that are less susceptible to climate and weather conditions and natural disaster such as fire, rain, flood has led scientist and engineers from different fields such as architects, civil engineers, material scientists, computer engineers and scientist to developed 3D printing system. A 3D printing system is trained using data from integrated design models which is operated by professional and can print as fast as meter per second. The adoption of 3D printing in construction has open the prospect of producing more complex shapes and buildings with lower associated cost and labour.

With advancements in internet of things (IoT) Big Data (BD) and Cloud Computing (CC) has open the gateway to digitalization of product and services. Compared with traditional construction the integration of these technologies along with 3D printing will enhanced social, technical, environmental and economic benefits. Despite the vast applications of these technologies in construction and management of smart homes, they are hindered by several challenges such as the concern for massive unemployment as a result of adoption of 3D printing in the industry, the lack of sufficient amounts of data to train and evaluate ML models and the issue of security and privacy.

Experts and academicians from various disciplines are working together to address these challenges. One of the ways forward is the creation of database platforms that allow uploading and sharing of construction data to aid in training of ML models. Developing an encrypted system to prevent attacks and the use of unique and secure logins such as fingerprints, eye detection, face detection and sophisticated passwords are some of the ways to address the issue of security and privacy. The shift away from traditional construction towards automated system is growing rapidly. The use of machines in construction industries have shown great potential, advantages and are gradually replacing the need of manpower which is creating concern globally. Addressing this issue require critical actions from both the governments and construction sectors.

Conflict of Interests

We declared no conflicts of Interests

Funding

No funding

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