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# Improving Citizens' Health in Underground Public Interior Spaces Through AI Powered Green Walls

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**Abstract**

In almost 600 BC, the Green Walls concept was presented. Most of the previous research has proved that the use of green walls in different types of interior spaces has its considerable merits in improving users' overall health and productivity. Interior Designers seem reluctant to integrate green walls in underground spaces due to its drawbacks as one of the most expensive man-made walls, needing scheduled water requirements, and its susceptibility to adversities such as fungi growth.

The current study offers an intelligent solution predicting the performance of self-sustainable green wall systems improving underground air quality. The system is mitigating the issue of the green wall's short life span. The sustainability of green walls and air quality in underground interior spaces is investigated by applying IoT and AI technologies.

Results of the present work show that different Random forests which an example of an ensemble learner built on decision trees. The Decision trees are
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extremely intuitive ways to classify or label objects models were generated compared and evaluated for accuracy and sensitivity. These Models were built simulating IOT-based-Air quality monitoring systems integrated with self-sustainable green walls. The Datasets selected included features like temperature close to that of the targeted public interior spaces like underground stations in Egypt. Predicting underground air quality has been conducted by indicating pre-defined parameters such as PM and CO. These results can evolve in the near future, enabling decision-making systems to predict the performance of similar self-sustainable multi-purpose green walls in maintaining underground space air quality..

**Keywords:** AI-IOT systems, Air quality, Public interior spaces, Sustainable green wall.

| **Nomenclature** | |
|---|---|
| **AI** | **Artificial Intelligence** |
| **AQG** | **Air Quality Guidelines** |
| **BIM** | **Building Information Modeling** |
| **CO** | **Carbon Monoxide** |
| **DT** | **Decision Tree** |
| **FAO** | **Food and Agriculture Organization for United Nations** |
| **IOT** | **Internet of Things** |
| **LWS** | **Living Wall Systems** |
| **ML** | **Machine Learning** |
| **PM** | **Particulate Material** |
| **SBS** | **Sick Building Syndrome** |
| **WHO** | **World Health Organization** |

## 1.Introduction

Public spaces have always been an integral element in the urban fabric, defining the form and structure of cities, and influencing the quality of urban life. Public spaces are highly diverse, which is why their quality is not always easy to assess. Various types and forms of public spaces are encountered in cities, including squares, streets, markets, parks, sidewalks, shopping centers, community centers, playgrounds, schoolyards, and urban interiors. Underground interior spaces which is the focus of the current work have evolved dramatically on the economic, technological, and social scales which has been in direct proportion to the rapid urbanization by the 21st century and previous research has proven its negative impact on humans' overall health either physically or mentally and that came in relation to multiple factors one of which is poor air quality and lack of sunlight. [1],[2]

Interior Design Solutions related to improving air quality are various, one of the most prominent alternatives that has proved its positive impact on human health are increasing green areas which has driven the innovation of new design approaches like biophilia. Green walls are one of the forms of increasing the green spaces vertically and it is a modern technology that is gradually finding its place in advanced contemporary cities in the world today. It is worth mentioning that one of the main reasons that encourages using the green approach in general is achieving sustainability on all scales, sometimes greening can be insufficient economically. [3], [4]

A Lot of Honest Research work has been dedicated to study the impact of AI-IOT Technologies on improving the performance of traditional buildings and with the assistance of these technologies buildings can get smart and even have the intelligence. Studies tried to focus on improving energy efficiency, thermal comfort, health, and productivity in the built environment. AI-IOT based techniques can be directed to achieve energy-efficient, self - sustainable green walls that can offer comfortable and healthy alternatives either above or underground.

### 1.1 Research Problem

Unhealthy underground public interior spaces that impacts citizens' health negatively especially air quality and the unsustainable design solutions offered to solve this critical problem like green walls.

### 1.2 Researcher Hypotheses

Some hypotheses should be taken into consideration to achieve the success criteria of this research. These hypotheses are:

- Green walls are one of the optimum options to improve underground interior space air quality leading to improving Citizens' overall health.

- Current available green walls have a lot of challenges that make them not fully sustainable due to the required higher cost.
- Artificial intelligence & IoT technologies will be merged offering a solution that creates a better, more sustainable version of green walls.

### 1.3 Research Aim

This research aims to study an intelligent solution predicting the performance of self-sustainable green wall systems improving underground air quality in Egypt. The system is mitigating the issue of the green wall's short life span. The sustainability of green walls and air quality in underground interior spaces is investigated by applying IoT and AI technologies. It improves the currently available Design solutions for the green walls to be more sustainable and multipurpose using Artificial intelligence to improve underground public interior spaces' air quality. This paper will highlight the importance of achieving full sustainability in any interior space. It will shed the light on the potential of Artificial intelligence and IoT in creating fully automated sustainable interior spaces in Egypt.

### 1.4 Research Methodology

The research methodology followed is shown in the following figure fig. (1), Accredited dataset is collected by imitating sensors' readings of a pre-established IoT system collecting air quality in underground stations, it also includes data collected from monitoring green walls. Pre-processing the data mainly involves removing repeated or faulty data then it is inserted in the Random Forest model selected where the predicted values are analyzed and tested compared to the real time data then the model will be initialized in IOT application that monitors the performance of green walls and its impact in improving air quality in underground interior spaces.

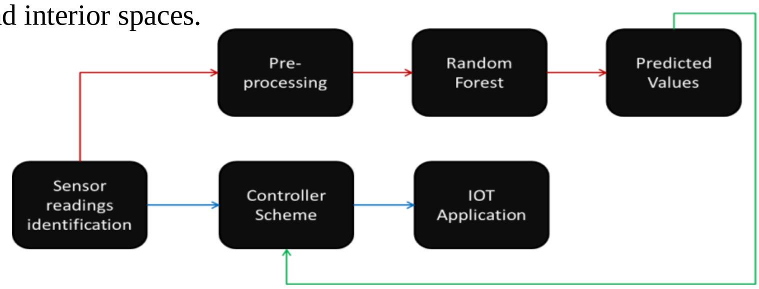


Fig. 1 Proposed Research Methodology

### 1.5 Research Limitations

As mentioned in the previous section, this research requires historical data on air quality index calculations and hydroponics parameters control measurements in Egypt's underground railway station. The availability of the required datasets is considered one of the research limitations that can be overcome using datasets in environments, similar to Egypt's underground railway stations.

## 2. Public Interior Spaces

In this section, main types of public interior spaces are shown and factors affecting people's perception of underground station spaces are mentioned in details and how green walls are expected to be one of the most promising alternatives that can help in achieving….. Finally, this aligned with Egypt's future vision is discussed as well, but before discussing this , the paper will show in detail what

### 2.1 Public Interior Spaces, Definition, Types and challenges

Interior designers have a huge role in providing healthy interior spaces to users either it is residential, commercial or hospitality type and the more complicated the interior space is (having several functions and being a large scale), the harder and more sensitive the mission is. Public Interior Spaces are considered the most challenging complicated systems, it is worth mentioning that there is some controversy on the word "public" , it has two meanings that are partially overlapping: accessibility and ownership.

Firstly, the term 'accessibility' denotes that these spaces are open to all, and can still be limited in time for practical reasons. As per ownership , public spaces can be both owned by public as well as private sectors [5] It can be illustrated that public spaces are open to all even for specific time of the day but are not necessarily public owned. In addition, public interior spaces in most cases are known to erase the borders between the indoor and outdoor space where the surroundings seem to flow into the interior space and vice versa, By this we can say that underground public interior spaces can be named to the following type of spaces which is the focus of our study as shown in Figure. 2.

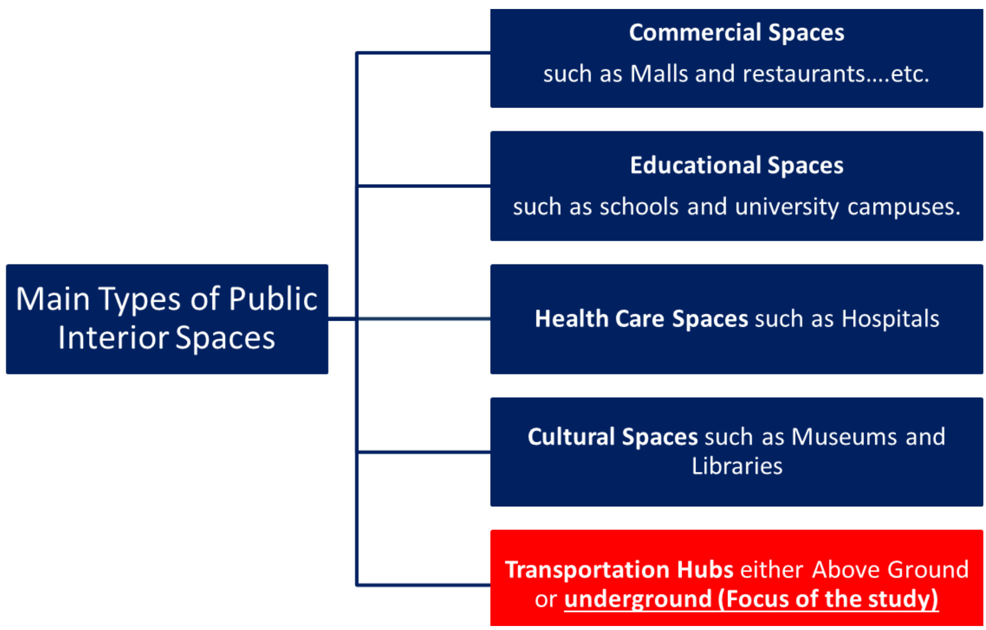

Fig.2 Types of public interior spaces

### 2.2. Underground station interior space potential and challenges

In this paper, we will focus on transport interior spaces represented in stations, particularly underground stations as a type of public interior space with a lot of challenges generally and in Egypt specifically.

2.2.1. Underground Metro Stations Potential Globally and in Egypt

More than 50% of the world's population live in cities and this is projected to increase to 68% by 2050 [6] and underground metro stations became the solution to cope with rapid urbanization and population growth in urban residents especially in Egypt being an overpopulated country. Unfortunately, Levels of air quality guidelines as recommended by World Health Organization (WHO) as shown in Table. ( 1 ) below has been exceeded in Egypt especially in large cities like Cairo.

Table.1 WHO Standards as (AQG) Air Quality Guidelines [7]

| Pollutant | Averaging time | Interim target | | | | AQG level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| $PM_{2.5}$, μg/m³ | Annual | 35 | 25 | 15 | 10 | 5 |
| | 24-hour[a] | 75 | 50 | 37.5 | 25 | 15 |
| $PM_{10}$, μg/m³ | Annual | 70 | 50 | 30 | 20 | 15 |
| | 24-hour[a] | 150 | 100 | 75 | 50 | 45 |
| $O_3$, μg/m³ | Peak season[b] | 100 | 70 | – | – | 60 |
| | 8-hour[a] | 160 | 120 | – | – | 100 |
| $NO_2$, μg/m³ | Annual | 40 | 30 | 20 | – | 10 |
| | 24-hour[a] | 120 | 50 | – | – | 25 |
| $SO_2$, μg/m³ | 24-hour[a] | 125 | 50 | – | – | 40 |
| CO, mg/m³ | 24-hour[a] | 7 | – | – | – | 4 |

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean $O_3$ concentration in the six consecutive months with the highest six-month running-average $O_3$ concentration.

The Air Quality Guidelines which will be followed through the study focus on some parameters such as PM10, PM2.5, Nox, SOx, CO, O3.  There are negative health impacts associated with the exposure to black carbon, mineral dust, sulfates, nitrates and ammonia known as Particulate matter (PM). Carbon monoxide is a colorless, odorless and tasteless toxic gas produced by the incomplete combustion of carbonaceous fuels. The Ozone ($O_3$) gas generated at at ground level is one of the major constituents of photochemical smog. Fuels combustion in the transportation/industrial sectors generates Nitrogen dioxide ($NO_2$) and Sulfure dioxides (SO2). [7-10]

Despite the need of underground stations, it still has its share of challenges represented primarily in its environment characteristics due to it being an enclosed one below the surface of earth which is prone to cause decreased oxygen concentrations and increased carbon dioxide concentrations [11,12], elevated humidity and temperature [13], increased toxic particle concentrations [14], and accumulation of radioactive radon [15].This , in addition to lack of natural sunlight ,all those factors can surly negatively impact users health, especially if they do use it on a daily basis which probably many of the citizens already do.

The Egyptian Government has taken action to face pollution challenges and climate change where there have been considerable amount of investments directed towards improving the public infrastructure specifically in the transportation sector as a part of Egypt's vision to 2030 as well as 2050, This vision is moving towards a more healthy and sustainable and greener tomorrow where Sustainable transport is a main pillar of the Egyptian carbon emission mitigation strategy [16].

2.2.2. Interior design role in solving the challenges facing Underground stations

An important question that we are attempting to answer in this study: Can a good design help in decreasing negative impacts on users' health?. With the help of the results published in the journal of Urban Design and Mental Health summarizing the factors having negative impact on human mental health during using different transportation stations , it is proved that it definitely can.The study summarized it to 8 main factors as shown in the figure below fig. (3). In this paper we will focus on how to achieve Comfort being one of the most important aspects and the number one priority to uses of transport stations based on the list [17]

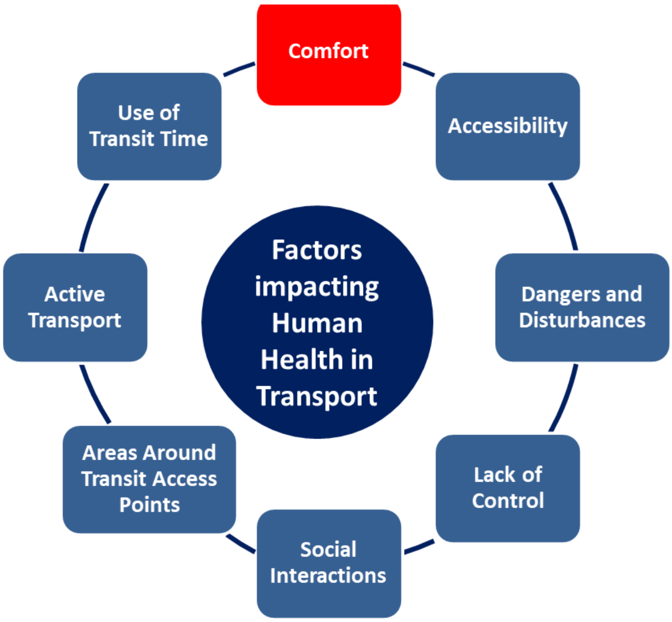


Fig.3. Summarizing factors impacting human health

In this regard, it is worth mentioning that comfort can be achieved through by keeping in mind noise, light, smell and temperature control, all which can be controlled through different interior design elements, and by even deeper investigation from the researcher's side all those factors can be achieved to a great extent through the usage of green walls.

Green walls as an interior design element can provide ecosystem services such as urban heat island reduction, water management, noise reduction, and improved air quality. and it has a great impact on how we users perceive the space which is one of the main objectives of any interior design project that influences the user's general experience through how user perceive the space and in this regard , it is worth mentioning that there are four types of perceptions fig.(4). [18]

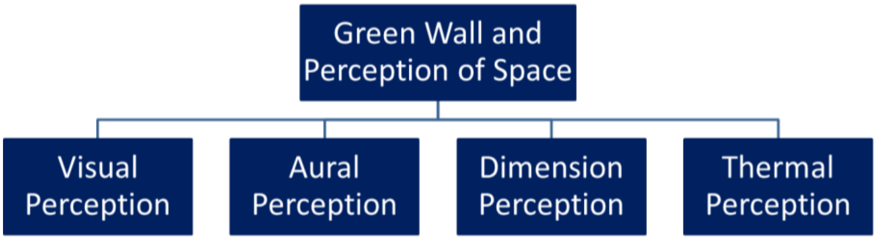


Fig.4 Green Wall Different Perceptions of Space

Green wall can theoretically target the four of them, The visual perception includes Form, color, substance, texture, and light. In this case we are talking about the green color of plants used which are proven to make the space feel a lot larger [19] and as a result indirectly influence the dimensional perception as well in addition to adding a pleasant aesthetic value to space, while achieving the thermal and aural perception is indisputable by giving a cooler effect to the space and reducing noise which is as well proved to have a great impact in it even better than some other cladding materials. And this is the main motive for choosing Green walls to solve underground challengeable environments and even improving from the current available versions toward more sustainable ones with the help of Artificial intelligence for creating better underground environments for healthier citizens and being aligned with the world's as well as Egypt futuristic visions towards a more sustainable tomorrow .

## 3. Green Walls

Green walls are vegetated vertical surfaces where plants are attached to the surface through various mechanisms. This term is referred to as an independent structure or integrated part of a building. In this study, it is vital to have a brief overview about the role of green walls in worlds' vision towards green interior spaces and their proven added value. In addition to that, The optimum type of green wall will be selected, summarizing the core challenges in installation, operation and maintenance, as well as the latest trends in underground applications worldwide and in Egypt. [20], [21]

### 3.1 World's vision towards Green Interior Spaces & It's Overall Value

Our cities today suffer from the lack of greenery and with the need to slow down the pace of urban life. As a part of the world's vision to achieve sustainability, the interior design world has recently encouraged utilizing several design approaches that are based on increasing green spaces. One of the most popular approaches is the biophilic design which is based on reconnecting humans with nature, this concept has been known from Almost 600 BC where the green Walls concept was presented referring to all forms of vegetated wall surfaces where it evolved over time contributing to the insertion of vegetation in the urban context without occupying any space at street level as shown in Fig. (5). [3], [20] , [22-28]


Fig.5 Integrating Greenery Systems on Buildings

Creating sustainable interior design is the process of forming and creating interior spaces by dealing with spaces and their internal components in an environmentally responsible manner. Greening systems can also make part of a sustainable strategy of urban rehabilitation and building retrofitting, encompassing three dimensions taken into consideration in our study as shown in the figure below fig.(6) [29,30]

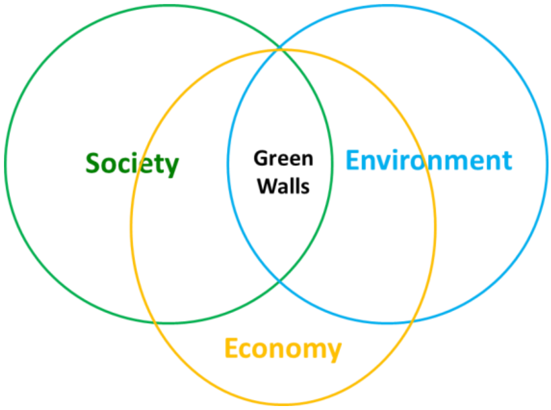


Fig.6 Green Walls between the three dimensions of sustainable Development

From the Environmental Aspect: Vegetation has the potential to improve the microclimate both in winter, functioning as a complementary insulation layer and recent studies show that green wall systems have an effect of evapotranspiration that can reduce solar radiations' impact controlling increased humidity and surface temperatures that can eventually contributes in the improvement of indoor thermal comfort and reduce energy demands for heating or cooling. [22].

From the Social Aspect: Green walls in urban areas have a therapeutic effect by inducing psychological wellbeing, increase property value and function as a complementary thermal and acoustic protection, general health of users has grabbed attention of the researchers for the longest time since the 60s trying to summarize different types of user sickness and health issues resulting from non well designed interior spaces, one of those most popular definitions trying to summarize the matter is what called Sick building syndrome (SBS) which is as a group of health problems that are caused by some poor factors in the indoor environment such as Uncomfortable temperature and humidity, chemical and biological pollution. [9]

From the Economical Aspect:  In Direct green facades offer a more sustainable economic solution that has low maintenance needs. One of the critical factors is Long materials durability that can minimize the operating cost while PVC material will have low fixed cost but due to its limited durability requiring its replacement more than once during buildings life expectancy. From previous research, it was found that direct/indirect green facades are relatively cheaper than LWS by a cost less than 75 €/m$^2$ [22]

### 3.2. Green walls in Underground Stations current state (World Wide & Egypt)

The main focus of the current study is to prove how to utilize the current technologies that can maximize the functional benefits of the green surfaces with respect to the building performance maintaining its sustainability specifically in underground spaces.

Regarding green walls in underground stations and by evaluating the current status and available applications, it is worth mentioning that there is almost no application of green walls in underground stations all over the world and all the available applications are considered as upper ground applications to stations' external building facade. One of the most famous examples of this is the Edgware road tube station living wall , Marylebone in London with the main target of reducing air pollution in London as shown in fig.7 and fig.8



Fig.7 showing Edgware road tube station living wall [31]
Fig.8 Zooming View of the living wall [31]

In Egypt, it is almost the same , yet the bright side is that as per Egypts' vision 2050, the main target is a "global - green and connected cairo" [30] which will be achieved through a series of projects already kept in consideration in different sectors including the transportation sector where the government is planning keeping in consideration a greener Cairo as well as started planning for underground parking to decrease the crowdedness off crowded areas in the different parts of the capital (e.g : Mohandseen area - Gamaet el dewal street ) which proves that the concept of underground and leveling is on the map and strongly which is the thing that enhances the value of the proposal being aligned with the country's futuristic vision by creating underground greener spaces. [31]

### 3.3. Green wall Proposed Model

In the previous research, Types of green walls have been divided into two main categories as shown in fig. (9) below; a) green façades and b) living walls. Living wall systems and green façades have different features affecting their advantages. Green Indirect façades are based on using climbing or hanging plants, which are either attached directly or indirectly to the wall. Direct green facades are the ones in which plants are attached directly to the wall while Indirect green facades which have been proposed in our solution include a supporting structure for vegetation. Indirect greening systems include continuous and modular solutions. [22], [32]

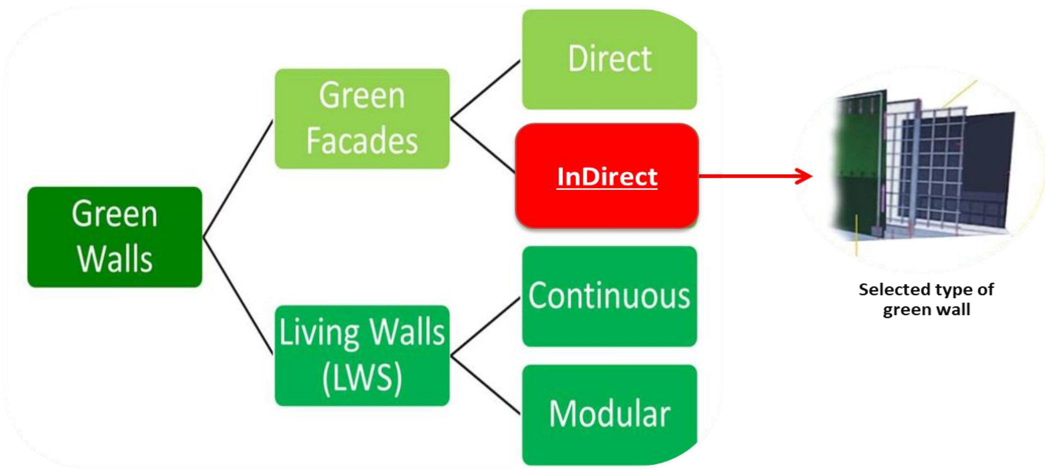


Fig.9 Types of green walls

#### 3.3.1 Design Requirements

Design and Performance Requirements in green walls have been identified, for example in the design requirements: (supporting elements, growing media, vegetation, irrigation and drainage), In order to achieve more efficient technical solutions and a better performance in all building phases (installation, maintenance and replacement). With the Development of Green Walls applications, The adaptability to more building types (e.g., commercial spaces, high rise buildings) has been identified as a requirement, construction methods (new or existing building walls) and types of surfaces (e.g., sloping surfaces, indoor partition walls and free-standing structures) is also the concern in the evolution of green wall system. [22]

With the aim to help designers and researchers in the evaluation of impact of the main elements of a vertical green system in underground stations, some criteria have to be taken into consideration and with the assistance of previous research studies a summarized SWOT Analysis taking the most common strengths, weaknesses, opportunities and threats of vertical green walls in underground interior spaces (stations) into consideration as shown in Table 2.

**Table . 2** SWOT Analysis on Vertical Green Walls [33]

| **STRENGTHS** | **WEAKNESSES** |
|---|---|
| ● Energy Saving<br>● Indoor Comfort<br>● Air Pollution Control<br>● Storm-Water Management<br>● Noise Reduction | ● Water Requirement<br>● Maintenance Cost<br>● Lack of Technical Data<br>● Untrained Designers<br>● Susceptibility to adversities |
| **OPPORTUNITIES**<br><br>● Longer Life-span<br>● Contribute to Urban Biodiversity<br>● Good Esthetic Appearance | **THREATS**<br><br>● Life Cycle Assessment<br>● Environmental Impact<br>● Life Cycle Costs<br>● Lack of Technical tools |

**Table**.3 FAO Standards for Irrigation Water [34]

| Categories | Parameter | Unit | FAO (Standard) |
|---|---|---|---|
| Salinity | EC | µS/cm | 0-3000 |
| | TDS | mg/l | 0-2000 |
| Cations | $Ca^{2+}$ | meq/l | 0-20 |
| | $Mg^{2+}$ | meq/l | 0-0.5 |
| | $Na^{+}$ | meq/l | 0-40 |
| | $K^{+}$ | meq/l | 0-20 |
| Anions | $HCO_3^{-}$ | meq/l | 0-10 |
| | $Cl^{-}$ | meq/l | 0-30 |
| | $SOz^{2-}$ | meq/l | 0-20 |
| Other | pH | 1 to 14 | 6.0-8.5 |
| | SAR | meq/l | 0-15 |

### 3.3.2 Proposed Model Selection Criteria

Our proposed green wall system shown in fig.10 below is addressing threats resulting from the unsustainable inadequate design of green walls assuring that the design must comply to have low impacts in terms of energy, water and raw materials. The plant selected is The Third Chinese evergreen (Aglaonema Commutatum) that belongs to the Araceae family that consists of around 21 species. This genus has been selected for fulfilling specific required criteria such as its ability to accommodate low light and poor ventilation, also it is fast growing and requires less maintenance, this beautiful shaped colored plant is relatively available in Egypt. The rooting of cutting of basal shoots is the main method of cultivating the Aglaonema species, this method is at high risk of pathogen transfer.

There are many techniques used to build green walls, one of which is the use of hydroponic cultivation systems. Growth of plants in hydroponic culture systems is easier than growing them in the soil to avoid soil pests and diseases, irrigation is less than the irrigation of the plants cultivated in soil. Also, an irrigation system in a hydroponic culture can be easily automated, root systems can be seen and root environments can be easily monitored and controlled avoiding over flows and drowning. As shown in the figure there are multiple layers of galvanized square tube wall that can perform insulation on the wall and there is an automated pumping system that supplies water from the water reservoir. [22], [35-39]

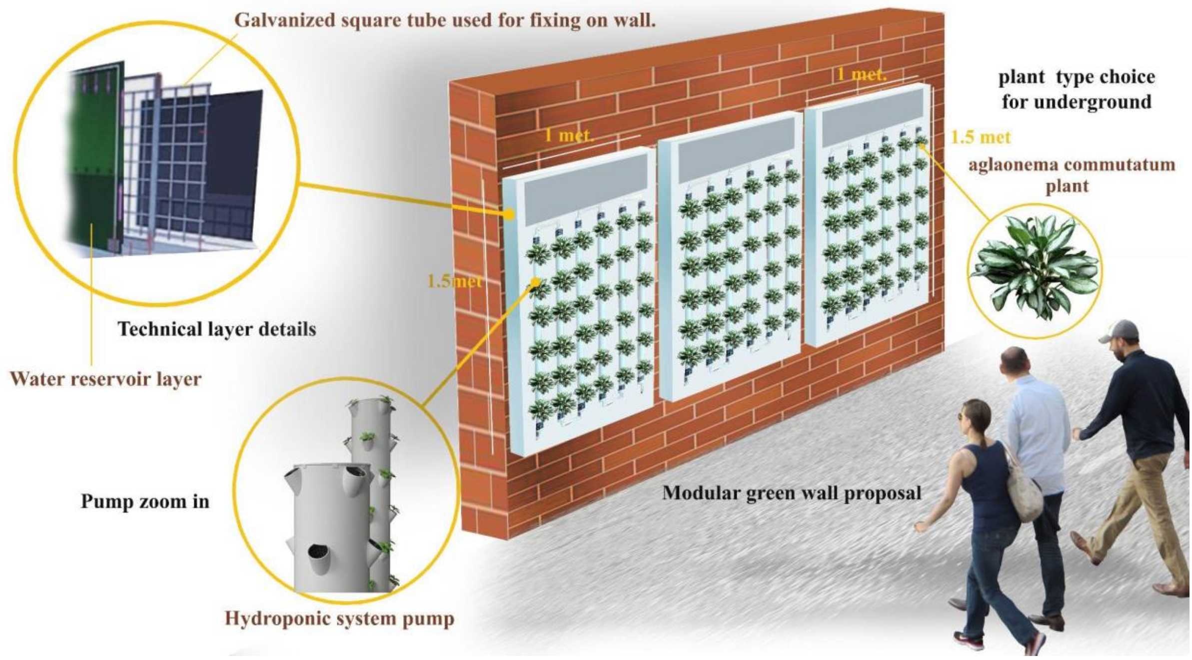


Fig.10 Modular Green Wall proposal

## 4. AI and IOT Technologies in the Design World

The Evolution of Technology Utilization through time has taken different forms The First Industrial Revolution, where the utilization of steam engines started in Great Britain in the 2nd half of 1700s till the fourth industrial revolution that came after digital revolution where describing an era where technologies like Artificial Intelligence, Autonomous vehicles or the Internet of Things are rapidly becoming vital in our daily lives, and with time they will evolve to become a necessity of our day-to-day life.

The Design world has been massively impacted by the evolution of technology as shown in fig. (11) , building information modelling (BIM) has become a digital tool enabling innovation that is utilized in the development of new buildings and facilities where AI can help in the optimization of design, construction and operation/facility management. With the help of AI and IOT Technologies, a large amount of data can be extracted from projects and with the help of the collected data can offer a variety of solutions that can be automatically generated using a different machine and deep learning models. AI is driving the development of intelligent buildings, making them self-learning and adaptive rather than just automated. Much research has been dedicated to using AI technologies in smart buildings, focusing on improving energy efficiency, thermal comfort, health, and productivity in the built environment. This section elaborates how existing AI-IOT based techniques can be directed to achieve energy-efficient, self-sustainable green walls that can offer comfortable, and healthy buildings. [40],[41]

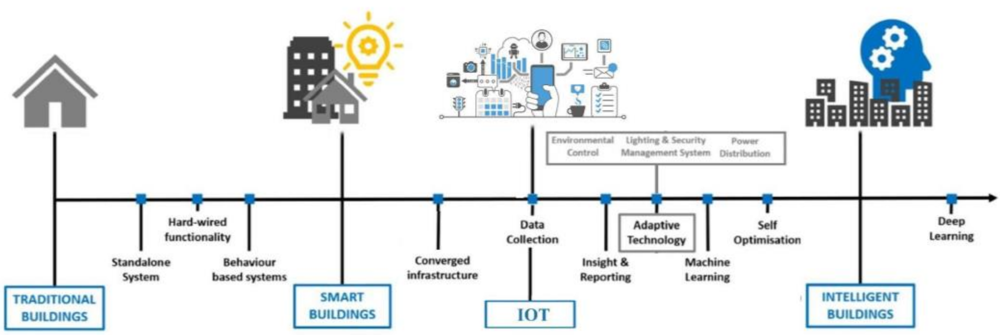


**Fig. 11 The Evolution of buildings from Traditional to Intelligent**

### *4.1 IoT Technologies in Agriculture & Design of Underground spaces*

The Internet of Things (IoT) is an emerging paradigm that evolved in the 4th industrial revolution era; this technology performs the communication between electronic devices and sensors utilizing the internet, which is present in the perception layer shown in Fig. (12). IoT technology has four layers. The first is the perception layer, in which the connection between the electronic devices and sensors is established. The second is the network layer, which plays a vital role in connecting all devices over a communication protocol achieved in this layer. The third layer is the application layer, which assists in the data analytics stage, device control, and reporting to the end users. Last but not least, the business layer gets the output data of the decision-making stage to the application for feedback according to the whole system.

IoT has proven to be an effective enabler for many industrial underground applications, including underground mining safety risk analysis and early warning management. Industrial IoT, on the other hand, can be difficult to implement because it necessitates the deployment of a large number of energy-constrained sensors and sensing units, and the wireless signals they send are lost due to data collisions, consuming node energy and reducing energy efficiency. As a result, for construction safety warnings in harsh industrial monitoring environments, real-time reliable transmission of sensing data under energy-constrained conditions is critical. Existing transmission schemes, such as Wireless Hart, WiFi, and others, cannot be directly applied to underground mining monitoring environments with energy-efficient requirements due to their high energy consumption.[42], [44]

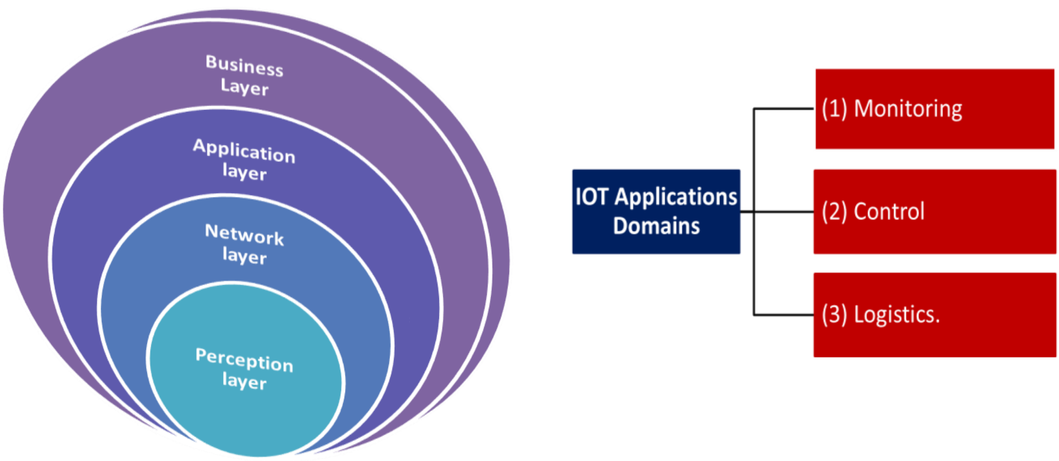


Fig.12 IoT Applications Domains [43]

In agriculture, IoT applications include smart farming, automatic irrigation, pesticide spraying, and disease detection. Sensors can be placed in various locations, such as the ground, water, and vehicles, to collect data. Cloud systems are used to store the collected data, and farmers use mobile phones to access the data via the internet. Previous research depicts the proposed approach for smart underground railway monitoring. [45], [46]

### *4.2 Prediction using Machine Learning*

Machine Learning (ML) prediction algorithms present a scalable and multidisciplinary method for data analysis that can have a significant impact on agricultural sustainability and Air quality index prediction for health saving. Appropriate modelling of plant growth dynamics and crop yields is also critical in hydroponic agriculture systems, as is effective resource management. [47], [48]

The use of machine learning algorithms (MLAs), which include artificial neural networks (ANNs), regression trees (RTs), random forests (RFs), and support vector machines (SVMs), in agriculture and air quality index modelling is considered a vital issue to save the main pillars of the sustainability which are water, food and health.

The following criteria are used to compare the modelling performances of several MLAs, including artificial neural networks (ANNs), regression trees (RTs), random forests (RF), and support vector machines (SVMs): the precision of predicted values; ii) the sensitivity to hyper-parameter estimation; iii) the sensitivity to training data size; and iv) the interpretability of model parameters.

The RF beat the other MLA techniques, according to the findings of applying the algorithms to hydroponic and air quality index (ANNs, RTs and SVMs). With different training parameters, the RF algorithm demonstrated excellent stability and resilience, as well as better success rates and ROC analysis outcomes. [49]

### *4.3 Decision-making (control) in machine learning*

Decision-making is a process involving decisions about specific events, especially sudden events. Depending on the degree of certainty of the problem description and solution, decisions are classified as structured, unstructured, or semi-structured. An unstructured decision is non-deterministic and depends on stochastic processes that provide different decisions according to its probability, whereas a structured decision is deterministic and has a known solution. Unstructured decisions primarily depend on the decision maker's preferences or experiences, whereas structured decisions do not involve any judgement on the side of the decision maker. A broad range of problems called semi-structured decisions exist between supervised and non-supervised decisions. [50]

AI and ML can help us in making the best decisions in decision-making situations especially when it comes to control several parameters such as PH, EC, humidity, water temperature, air temperature, and light intensity in hydroponic systems. Fuzzy Logic, Decision Tree, and Neural Networks are the most often used AI and ML tools for decision making (control) in hydroponic systems. [51]

### *4.4 Decision Tree as a Framework for Intelligent Decision Support*

Decision trees (DTs) are a popular machine learning (ML) model for making decisions (control). Ensemble approaches such as decision trees and random forests are commonly utilized in machine learning. Decision trees are a supervised learning system in which input is constantly split into distinct groups based on specified factors. It's a tree-based technique in which any path from the root to the leaf node is characterized by a data separating sequence until a Boolean result is obtained. It is a hierarchical exemplification of nodes and links in knowledge relationships. Nodes indicate purposes when relations are used to categorize. [52], [53]

DTs are one of the potent approaches utilized in a variety of domains, including machine learning, image processing, pattern recognition, and decision making (control). DT is a sequential model that effectively and cohesively connects a series of fundamental tests in which a numeric feature is compared to a threshold value in each test. [54], [55]

The numerical weights in the neural network of connections between nodes are far more difficult to construct than the conceptual rules. DT is primarily used for grouping purposes. Furthermore, in Data Mining, DT is an often-used classification model. Each tree is made up of nodes and branches. Each subset defines a value that the node can take, and each node represents features in a category to be categorized. Decision trees have a wide range of applications due to their ease of analysis and precision across numerous data types. The structure of DT is depicted in Fig. 13. [56], [57]

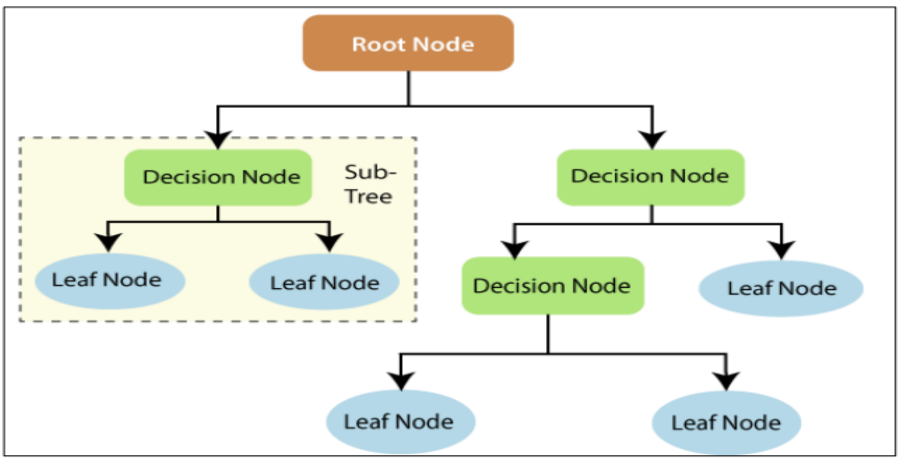

Fig.13 Decision tree structure

Models can learn or understand from experience, make sense of ambiguous or contradictory messages, respond quickly and successfully to a new situation, solve problems using reasoning, deal with perplexing situations, understand and infer in ordinary, rational ways, manipulate the environment using knowledge, think and reason, and recognize the relative importance of different elements in a situation so that's what distinguish the use of machine learning in decision making (control) over traditional ways. [58] After the process of collecting data from sensors, the readings send to ML model in order to come out with decision needed to take and it has to be known that the greater the number of datasets analyzed, the more accurate and reliable the ML model will be. [59]

### *4.5 Proposed schematic Diagram.*

As it mentioned before, this paper mainly uses ML model for decision-making and control which had to be firstly trained well by supplying datasets as an experience to deal with inputs (readings came from sensors) because the greater the number of datasets analyzed, the more accurate the ML model will be. Secondly, the ability to deal with insufficient and unreliable data as it might be sometimes inaccurate readings come from sensors. Thirdly, the ability to deal with more than one parameter as in hydroponics and air quality parameters there are many parameters needed to be handled to reach a full control system in the hydroponic system such as PH, EC, air temperature, humidity, water temperature, water level. On the other hand, some parameters should be measured for the air quality index modeling such as $CO_2$, CO, $NO_2$ and PM in the atmosphere that affects the air quality negatively. Finally, after the modeling of the hydroponic and air quality systems has been accomplished on the Raspberry PI and saved on the IoT dashboard and a backup server, based on the feedback received from these models, the control processes are deployed on the microcontroller unit to send the required commands to the actuators like fans and pumps to take an action suitable the required outputs to keep the system stability and keep it fully automated. All these processes are monitored through the IoT dashboard. The proposed schematic diagram for all these scenarios is shown in figure 14.

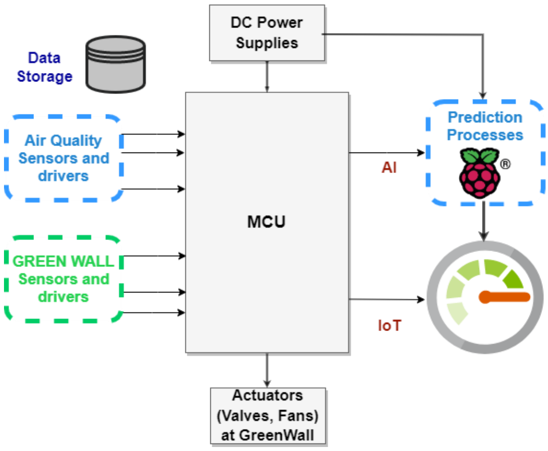


Fig.14 Proposed Schematic Control Scheme

## 5. Results and Discussion

Results of the present work show that Random Forest models were generated, compared and evaluated for accuracy and sensitivity. These Models were built simulating IoT-based-Air quality monitoring systems integrated with self-sustainable green walls.

The Datasets selected are licensed under a CC BY-NC 4.0 license, the Pennsylvania State University © 2022. It includes features like a ventilation factor close to that of the targeted public interior spaces like underground stations in Egypt since there were no available data sets that could be reached. The code was implemented via Google Colab.

Predicting underground air quality has been conducted by indicating pre-defined parameters such as PM and CO. The performance of green walls has been estimated with the assistance of several parameters, one of which is Relative Humidity. These results can evolve in the near future, enabling decision-making systems to predict the performance of similar self-sustainable multi-purpose green walls in maintaining underground space air quality.

Random forests are an example of an ensemble learner built on decision trees. Decision trees are highly intuitive ways to classify or label objects. Based on Table 1, the coding of the random forest has been applied to a dataset including three parameters: CO2, O2, and Vent. Where Vent indicates the ventilation factor that has been calculated based on the readings of the other parameters. It also determines the total volume of air in underground space per minute. A random sample of 80,000 readings has been used. In the random forest classification process, branches are built to reduce the calculated error. To achieve less error and test the classification code, the Gini impurity index has been calculated. The higher the Gini index, the more misclassification there is. Therefore, lower values of the Gini Index provide better classification. For the used dataset with sample = 1000, the Gini index is 0.997576. The model to fit the used dataset is shown in Figure 15.


## 5. Conclusion

This research suggested an integrated work that combines three features working together to add sustainability to the green walls in public interior spaces, especially in underground stations. It combined AI and IoT technologies with the positive effect of green walls in underground stations in Egypt. It also provided a brief overview of ensemble estimators, specifically the random forest - an ensemble of randomized decision trees. Random forests are an effective method with several advantages: Because of the simplicity of the underlying decision trees, both training and prediction are extremely fast. Furthermore, because the individual trees are independent entities, both tasks can be easily parallelized. The nonparametric model is highly flexible and can thus perform well on tasks under-fit by other estimators. Random forests have the primary disadvantage of being difficult to interpret.

Regarding underground interior spaces , there are no current direct implementation of green walls in underground stations despite the benefits  of using it on users that was previously discussed in detail .In addition , the data sets available was a clear limitation and needs further  quick investigations  and , for greener more sustainable underground stations aligned with Egypt's vision 2050 . Regarding the current state, we suggest implementing the current proposal in some stations that really suffer air quality issues such as translational stations such as Shohadaa, Sadat, Ataba. Based on the study, we suggest that the best place to be embedded at is the most crowded spots at the intersecting points between the escalators.

## 6. Recommendations

Some recommendations must be taken into consideration to apply such research regarding the green walls structure:

1. Start implementing the proposed green walls in underground stations, Starting with existing underground metro stations and especially transitional ones (ex: Tahrir ..etc) due to its positive effect that has been already proven through several studies, specifically in zones that indeed suffer air quality issues due to being overcrowded. E.g. line transition area zones such as Shohadaa, Sadat and Ataba.
2. Based on what has been scientifically based regarding the benefits of green walls on user health as well as Egypt's future vision 2050 regarding a greener and more sustainable transportation system, using green walls should be kept in consideration currently while planning and designing new underground stations.
3. Generating a portable green wall from the generated proposed version could be a real added value to the product to make it easy to be moved from one zone to another as per interior space air efficiency.

Regarding AI and IoT technologies used in underground stations:

1. A greater focus on generating datasets corresponding to Egypt's state for underground is a must, as this was a limitation of the current study.
2. Thinking about how can Ai help in changing the shape of green walls with different effects which can directly impact user perception of space when using underground stations, adding a fresh touch and giving a sense of security indirectly by giving an impact that stations are continuously upgraded, update and being taken care of and as a result reflecting a sense of belonging and appreciation to citizens in-directly.

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