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Contents

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Towards Autonomous Micropipette Positioning in Eye Surgery by Employing Deep Learning Algorithm in Micro-Cannulation

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ABSTRACT

Eye surgery, more precisely the retinal micro-surgery involves both sensory as well as motor skills. This is confined within human boundaries along with physiological limits for maintaining consistent steadiness, the ability to feel small forces and accuracy. Despite these assumptions to leverage robots in all types of surgery, multitudes of challenges have to be confronted to reach complete development. The deployment of robotic assistance in ophthalmologic surgery also faces the same challenge. This work focuses on the autonomous positioning of a micropipette that is to be mounted on a surgical robot for performing eye surgery. Initially, multiple microscopic images of the given micropipette along with its shadow are collected. These images are treated or filtered by using the Enhanced Gaussian Filtering (EGF) method. The so-obtained filtered image is partitioned or segmented by Bee Colony Optimization (BCO) into three segments: micropipette, eye ground and shadow of the micropipette. A new Modified Convolutional Neural Network (MCNN) is leveraged by the robot to perform eye surgery that learns the microscopic images with their ground truth. This MCNN uses automatic feature extraction and estimates micropipette regions with their shadow by examining a microscopic image and its tip. This is tapped for developing autonomous position control in robots. The selected micropipette is found to be positioned at a 99.56% success rate with a mean distance of 1.37 mm from the eye ground that is simulated.
Discipline: Artificial Intelligence, Healthcare, Applied Information Technology

Keywords: Artificial Intelligence;Machine Learning;Deep Learning;Robotic Surgery;Eye Surgery; Microcannulation; Enhanced Guassian Filtering;Bee Colony Optimization;CNN;Image Processing

1 Introduction

1.1 Information

Eye surgery, more precisely retinal micro-surgery, necessitates sensory as well as motor skills that mimic human boundaries along with physiological limits with consistency, accuracy, steadiness, and the potential to isolate the minute forces that are involved in the operation [1]. Besides the benefits of deployment of robots in medical surgery and despite the efforts placed for further development, this field faces a multitude of challenges to impart robots in real-time. The field of surgical ophthalmology also suffers from the same issue. The first robot-assisted ophthalmology-based retinal surgery was performed after 30 years after the publication of the first experimental papers pertaining to the subject that too in-human presence [2]. Artificial Intelligence (AI) through sourced a few decades ago, but it has now emerged as indispensable technology, especially in all surgeries and ophthalmology. This time gap was mainly due to the hampering of the technological advancements to realize AI as a tool for implementing novel processing methods.

The primary technique among technological advancements is the processing prowess of Graphics Processing Units (GPU) for Machine Learning (ML) [3]. It is evident that the notion of robots is to perform repetitive tasks mostly, but AI and ML are closely related with proven abilities to design new concepts to resolve problems autonomously through perceiving and understanding. The ultimate implication of exploring these abilities is that future machines may intricate into the domain which was once delineated as human-reserved [4]. Though the capacity of AI/ ML can be witnessed strongly, the current marketing promises as well as the hype created outnumber its pace of development. However, these robotic systems are integrated with ML that significantly enhancing the quality and precision of robot-assisted retinal surgery, which can be seen as a major breakthrough in the discipline. In addition, a lot of research comprehensively analyzes the recent technological advances in the domain of retinal robotic surgery by throwing light on the bottlenecks and limitations, apart from briefing the rationale of AI in robot-assisted retinal surgery [5].

As a matter of fact, particularly in retinal microsurgery, it has been discovered that human precision is best between 20 and 40 m. According to reports, the average human tremor has a peakto-peak value of about 100 m. The force indicated in the earlier work that is sufficient to tear the rabbit's retina is close to 7.5 mN [6], which is the mean human threshold for increased tactile sensibility. In this case, the stability, accuracy, and sturdiness of the robot are quite helpful handling delicate intraocular surgeries. The development of neural networks [7], their improvements in image processing, and the notable rise in data utilization [8] may eventually increase the efficiency and safety of robotic techniques used in eye surgery.

Apart from rendering new data sources, surgical visualization systems like “heads-up surgery” integrate Augmented Reality (AR) during the surgery. Virtual Reality (VR) systems like Eyes Surgical as well as Deep Learning (DL) tracking methods can also be leveraged with robotic control. This will definitely aid in training, improving and testing these systems to eliminate iatrogenic injuries. The improved data is the pedestal of progress in advancing AI, improved safety, enhanced efficacy and inclined reliability which are some of the potential outcomes of the integration of robotics into the discipline of ophthalmology. Several barriers exist to end-user adoption of robotics not confined to size, costs, functional limits, human acceptance, accuracy and more importantly, yielding better outcomes with safety.

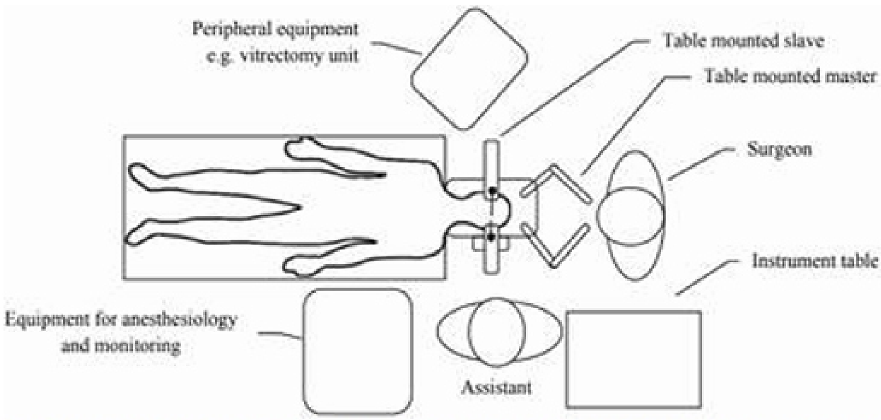

Figure 1: A typical operation room layout for eye surgery-Master Slave surgical process

With this motivation, this work proposes deep learning-based position finding of the micropipette attached to the surgical robot during eye surgery. Eye surgery, or in particular, vitreoretinal eye surgery, is an application where a manually or tele-operated robotic system assists the surgeon in performing the surgical routine. This robotic system is desired to be a master-slave system, where the slave system performs the actual surgery, controlled by the surgeon at the master as shown in Fig.1. As such, it can bring stability to enhance the surgeon’s surgical skills, while the surgeon’s knowledge and experience can still guide the process. This work presents some background information on robotics and describes some specific applications in medicine and vitreoretinal eye surgery.

It is preferred to maintain the current operating room layout, where the patient and peripheral equipment is within arm’s reach. A table-mounted slave system is compact and contributes to this [9].

The paper deals with an autonomous vitreoretinal eye surgery robot along with the accuracy-enhancing approaches to reach the target on eye ground. This robot ceases to be switched to the autonomous injection, which is also to be developed as a part of the work. The primary contribution of the work is as follows:

• Describing the working of autonomous positioning of a given micropipette along the depth direction by tapping its shadows where the image pre-processing is done using enhanced Gaussian (EGF).

• Segmentation of the given micropipette position and shadow of the micropipette, along with eye ground regions is done using Bee Colony Optimization (BCO).

• Finally, automatic feature extraction and the prediction of a label based on a Modified Convolutional Neural network (MCNN) for determining the shadow region that has an unclear border in the image, where stochastic max-pooling was injected to replace the standard average stochastic maximum pooling and maximum stochastic maximum pooling used.

• The positioning of the micropipette for eye surgery assists the robot automatically, which is done through a visual servo control method augmented with planar motion.

• The suggested method is particularly practical since, during vitreoretinal surgery, in particular, surgeons frequently use shadows to place tools along the depth axis. Astigmatism has little effect on how shadows are used in the end.

This paper is organized as follows. Section 2 describes the related work on eye surgery robots using ML and DL methods. Section 3 proposes Autonomous Positioning of the micropipette tip using the MCNN technique. Section 4 details the experiment that is done to assess the proposed method with discussions on the results, and the conclusion and future research directions are briefed in Section 5.

2 Literature Review

This section elaborates on the usage of ML and DL as a part of modern surgery, with a special focus on AI issues. The advancements of ML and DL will enable surgeons to deploy more autonomous actions in the surgical process. Tayama et al., [10] developed a novel method of automatic positioning of robotic arms by tapping the shadow of surgical instruments involved in the surgery. The microscopic image is partitioned into 3 regions: a micropipette, shadow of the micropipette, and eye ground through the famous Gaussian Mixture Model (GMM) augmented with Kalman filters. Li et al., [11] designed low-cost yet robust Densely connected CNN (Dense CNN) that could sense 9 or 36 directions of gaze computation to control the surgical robots. The surgeons can effectively control the developed robot by mentioning the beginning as well as ending points of the surgical robot through an eye gazing mechanism. These surgical robots can be managed to progress in 9 directions by obtaining the information from the controllers' eyes gaze.

Li et al., [12] proposed a probe-based confocal laser endomicroscopic system (pCLE) which acts as an imaging modality for enhancing the diagnosis. The capability to view the retina at a more granular cellular level provides information that is important to foresee the surgical results. Enhanced image quality, and smoother motion, with the decreased workload, can be achieved with hybrid control frameworks. But few researchers concentrated on it during the surgery. This is indeed a big challenge due to the high deformation of the iris and the occlusion that is inherently caused by instruments that are used in the surgery. A new real-time iris tracking system that is based on a regression network is given by Qiu et al., [13] that meets the accuracy as well as speed requirements demands of the ophthalmic robotic system. This system employs low level visual features with high-level semantic meanings that are collected from different layers to extract and capture the discriminative representation of the target (iris). The method for tracking objects involves looking through the windows with the best classifier scores. To locate the iris center, the Scale Invariant Feature Transform (SIFT) [14] is used [15]. Through PCA, a model in the shape of an eyelid is created and used to follow a particular iris [16]. According to some experts, template matching is still an effective method for identifying the iris. The feature extraction from photos is constrained by the feature representation's incapacity to handle more complicated real-world settings. The surgical scene typically contains more occlusion of the actual surgical tools being utilized. Consequently, the handcrafted features won't be enough to monitor the iris for the creation of an ophthalmic robotic system.

The features extracted from CNN make a bigger contribution to state-of-the-art object trackers. These features display a very strong representation of inherent semantic information of the pertaining target. This has indeed attracted greater research interest. Li et al., [17] designed a cascaded CNN to isolate the eye from facial images. The CNN can categorize the underlying region as left/right eye and the next CNN is employed for detection. Harini used ensemble learning in ResNet10 to track the eye [18]. Wolfgang et al. [19] suggested a double CNN for the detection of pupil position. These proceeds in two phases, the pupil position are identified by the first CNN while the second is used to refine its position. Hoffman et al., [20] proposed a CNN for eye detection, which incorporates a segmentation to learn the relative significance of the pupil as well as the iris. Though the DL methods outperform the hand-crafter and correlation filter methods, most network-based trackers are incapable of achieving real-time tracking mainly because of the online training. The multi-loss objective function is constructed to obtain improved overlap precision. These modifications eventually enhance the accuracy of tracking in the underlying ophthalmic robotic system.

In order to predict the occurrence of negative occurrences from a relatively brief history of temporal sensor readings, He et al. [21] introduced a Recurrent Neural Network (RNN). The robot is managed with a variable admittance controller to prevent it from tapping into undesirable situations. Through microscope-integrated Optical Coherence Tomography (MI-OCT), Zhou et al. [22] demonstrated a more reliable framework designed for needle identification as well as localisation relevant to the sub-retinal injection. The results show that the suggested strategy can localize the needle more precisely with a confidence level of about 99.2%. The already existing ML posts multiple challenges, like the demand to process a voluminous amount of data, iterative model training, and tuning the model according to various scenarios. But with the advent of DL, it definitely possible to effectively train an end-to-end DL model to resolve complex tasks.

3 Method

The work presents a more generic and robust framework for detecting the needle and localization of the same in the process of sub-retinal injection by examining microscopic images using DL. This method progresses through three main steps: image pre-processing, segmentation and locating the needle in segmented images. Pre-processing of the microscopic images is done through EGF. Then the segmented image fragments are fed into BCO for detection of the needle with its localization. The developed MCNN estimates the regions of the micropipette and its tip positions along with its shadow from a real-time image. The planar positioning is done through the visual serving method [24]. The utilized micropipette is advanced to the eye ground till the distance of the micropipette's tip and its corresponding shadow is less than or equal to the already predefined threshold. Therefore, the robot could effectively and accurately reach the eye ground and also stop safely before it establishes contact with the surface. The experimental results indicate that this method can vividly localize the needle with a good confidence score of 99.2%. The generic framework of the fore mentioned methodology is given in Fig.2.

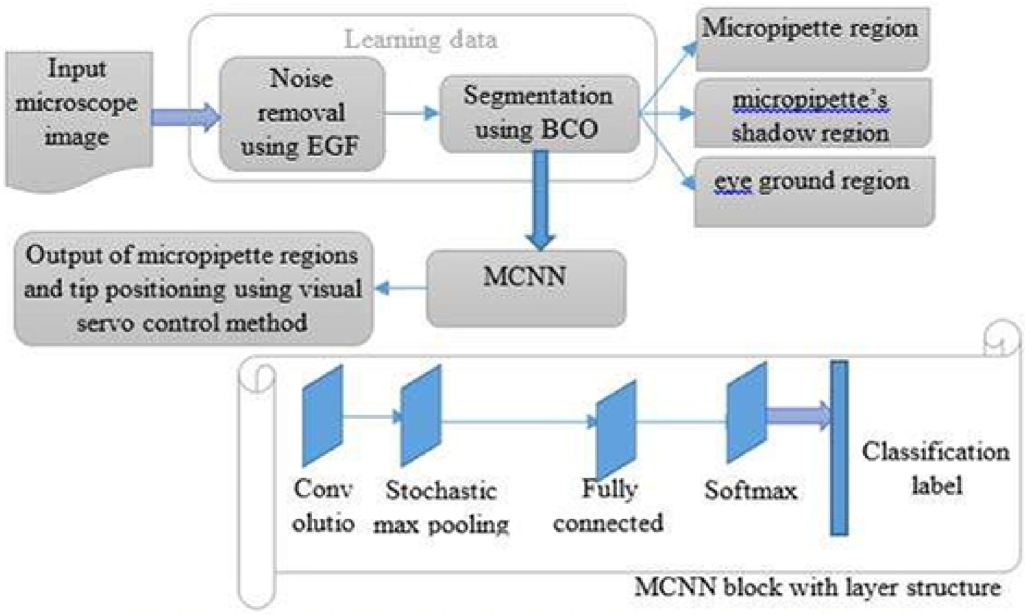

Figure 2: General framework diagram of the proposed methodology

3.1 Image Enhancement Using Enhanced Gaussian Filtering

Multiple microscopic images of the micropipette along with its shadow are obtained by varying the position of the micropipette and ambient conditions. After this, these images are segmented and the components are labelled. For better visualization, the micropipette, its shadow, and its background are rendered in different colors namely blue, red, and green, respectively. The pairs of microscopic image with ground truth data are employed in preoperative learning through the MCNN model. The EGF isolates the pixels with gray levels ranging from 0 -255 as noise. It restores the noise pixels through a Gaussian filter by estimating the noise density. Table 1 enumerates the parameters used in the proposed method.

Table 1. Parameter and Description of Proposed Methodology

Parameters	Description
$P_{i,j}$	microscopic images pixel, $i, j = 1, \ldots, L-1$
$g_{i,j}$	Gray level of $P_{i,j}$
Ω	$\omega \times \omega$ filtering window
$Res_{i,j}$	the restored gray level of $P_{i,j}$
$P_{m,n}$	neighboring pixel of $P_{i,j}$
$\varpi_{m,n}$	weight of $P_{m,n}$
σ^2	adaptive variation
nd	noise density
$s_{ij} = x_{ij} + \Re_{ij}(x_{ij} - x_{kj})$	BCO swarm search
k	Food source $k = \{1,2,\ldots,NS\}$
NS	number of food sources
x_{kj}	randomly generated k food source
$\Re_{ij}$	random number
$(\dot{m}, \dot{n})$	optimum 2-dimensional vector of the objective function
$\varphi(m,n)$	two-dimensional entropy
E_m	two-dimensional entropy of micropipette
E_e	two-dimensional entropy of eye ground regions
(m,t)	threshold value
R	Region
RP_1 and RP_2	probabilities of Regions 1 and 2 respectively
MC	maximum cycle number
D	Population size on search space
X_i	New solution
x_i	feature vector
l_i	Label of microscope image
$layer$	serial number of the layer
RF_j	the receptive field of the input layer
y_{max}	Result of pooled maximum value
y_{avg}	result of average pooling
Prb_i	Probability for value v_i
$y_{stochastic}$	result of stochastic pooling
GL_c	global loss of classification
GL_r	global loss of regression
Prb_i^*	the indicative value that corresponds to i-th candidate detection box
ap_i	coordinate vectors of the micropipette's detection box
ap_i^*	coordinate vector of the tip point that corresponds to the calibration box that depicts the shadow
λ	Threshold value
N_r and N_c	Normalized regression and classification respectively

For any given microscopic image with a pixel *Pi,j* with gray level *gi,j* the EGF method isolates the noisy pixels for the specified *I* and *j=1,...,L-1*.if the *gi,j* is 0 or 255, then the EGF decides the pixel *Pi,j* as noise. Otherwise, the *Pi,j* is delineated as noise-free. This noise isolation method allows reduces the wrong detection to 0. But sometimes it may detect noise-free pixels pertaining to the gray levels 0 as well as 255 as noisy, thereby generating false positives. This miss detection permits the noise-free pixels to undergo unfavorable filtering that may result in a blurred image. Apart from this, the inaccuracy of this method that is caused by the false alarm may adversely affect the performance of noise density estimation as well as the process of adaptive variance determination embedded in the Gaussian filter that is commonly used as a noise restoration technique.

The fore mentioned EGF method replaces the noisy pixel with its weighted average of the filtering window of fixed size. These weights are determined by a Gaussian filter augmented with the adaptive variance. The comprehensive noise restoration process in the EGF is given as:

For any detected noisy *Pi,j* indicates filtering window that is centred at *Pi,j*. The value of is set to 9.

Form a fresh set *N* excluding the noisy pixels at gray levels 0 as well as 255 at Compute the weighted mean of the pixels as restored gray level ($R_{esi,j}$)

$$Res_{m,n} = \frac{\sum_{P_{m,n} \in \mathcal{N}} \mathfrak{w}_{m,n} * g_{m,n}}{\sum_{P_{m,n} \in \mathcal{N}} \mathfrak{w}_{m,n}} \qquad (1),$$

The terms $g_{m,n}$ refers to the gray level and $\mathfrak{w}_{m,n}$ is the weight of $P_{m,n}$. The coordinates (i,j) as well as (m,n) respectively indicates $P_{i,j}$ and it's neighbor $P_{m,n}$.

Weight $(\mathfrak{w}_{m,n})$, is computed using the Gaussian function as:

$$\mathfrak{w}_{m,n} = \exp\left(-\frac{(m-i)^2 + (n-i)^2}{2\sigma^2}\right) \qquad (2),$$

The parameter σ is also empirically set as

$$\sigma = \mathrm{nd} + 0.2 \qquad (3)$$

σ^2 is the adaptive variance of a given Gaussian function. The term nd indicates the noise density which is computed as the ratio of the count of detected noisy pixels with a cumulative count of pixels in the entire image.

3.2 Segmentation Using BCO

The images that were pre-processed are categorized or segmented into micropipette, the shadow of the micropipette, and eye ground regions. Every pixel of the regions is labelled to be deployed as a ground truth. The proposed MCNN is employed by an eye surgery robot to study the microscope images with their ground truth through HSV color as features. The performance of this segmentation completely depends on local as well as global searching capability. Hence, the method of collecting honey forms the motivation for BCO and is given as $s_{ij} = x_{ij} + \mathfrak{K}_{ij}(x_{ij} - x_{kj})$. The term x_{kj} is randomly generated where $k \neq i$ (food source). The value of $k = \{1,2,\ldots,NS\}$. NS indicates the total count of food sources available. $\mathfrak{K}_{ij}$ is assigned a random value within $[-1,1]$. The search step of the insect is estimated as $(x_{ij} - x_{kj})$. The food source (k) is chosen around its surroundings. The popular Levy flights are injected to aid the foraging behaviors of bees to improvise the development of the algorithm and also to reinforce its capability to move away from local extreme values. Also, BCO uses global optimal solutions as well as individual extremes as a part of searching in observation bees. This collaboration among the populations adds up to global convergence. When the values$(\dot{m},\dot{n})$, are maximum, then the gray level pixels of the object as well as its background will be uniform. The objective function for finding the optimal threshold $(\dot{m},\dot{n})$ is taken as the popular maximum 2D entropy threshold as given by:

$$(\dot{m},\dot{n}) = \arg\max_{0\le m\le L-1} \max_{0\le t\le L-1}\big(\varphi(m,t)\big) \qquad (3),$$

This algorithm tries to achieve this value that can effectively maximize $\varphi(m,t) = E_{\mathrm{m}} + E_{\mathrm{e}}$. The value E_{m} is the 2D entropy of the micropipette. The value E_{e} is 2D entropy of eye ground regions.

$$E_{\mathrm{m}} = -\sum_{i=0}^{m}\sum_{j=0}^{t}\frac{RP_{ij}}{RP_1}\ln\left(\frac{RP_{ij}}{RP_1}\right) \qquad (4),$$

$$E_{\mathrm{e}} = \sum_{i=m+1}^{L-1}\sum_{j=t+1}^{L-1}\frac{RP_{ij}}{RP_2}\ln\left(\frac{RP_{ij}}{RP_2}\right) \qquad (5),$$

A 2D histogram can be constructed using 2D entropy modelling. The fixed threshold value (m,t) is partitions the 2D histogram into 3 rectangular zones namely: Regions 1-3. Region 1 pertains to the micropipette while Region 2 represents its shadow. Region 3 clearly indicates the ground eye regions. Generally, region 2 is ignored. The estimated probabilities of the first and second regions are given as $RP_1 = \sum_{i=0}^{m} p_{ij}$ and $RP_2 = \sum_{i=m+1}^{L-1}\sum_{j=n+1}^{L-1} p_{ij}$, respectively. A small difference in the gray level pixel yields great 2D entropy. If the 2D entropy is large, then the gray-level distribution within a class is assumed to be more uniform. This work attempts to maximize the 2D entropy of the target along with its background classes to achieve segmentation. The complete flow diagram is shown in Fig. 3. The BCO intends to resolve maximization problems. Hence, its objective function is maximized as the reciprocal of $(\dot{m},\dot{n})$. The complete pseudocode of the proposed BCO is presented below.

Input: Pre-processed images as the number of source of bee NS, the size of the population is given as D. The solution's dimension is D. The count of the honey-collecting and observation bees are set as initial iterations with Cycle = 1 whose maximum value is MC

Begin

Initialize the parameters pertaining to the population. Eliminate solution as well as upper bound of iterations MC.

Assessing $x_{ij}, (i = 1,2,\dots,NS, j = 1,2,\dots,D)$ at Cycle = 0, limit = 0.

Do

// honey collecting bees

For the value i =1 to NS then do

generate the new solution

$X_i = X_{min} + rand(0,1)(X_{max} - X_{min})$ and $fitness_i = f(X_i)$

Evaluate $x_{ij}(n)$.

If $(x_{ij}(n+1)$was superior to $x_{ij}(n))$

replace by $x_{ij}(n)$ by $x_{ij}(n+1)$

Else

Increase the iteration number by 1

End If

End For

Record the optimal or best solution X_{best}.

//observation bees

For the value $i = 1$ to NS

If the condition (rand < RP_i) holds

Generate the new solution

$X_{ij}(n+1) = X_{ij}(n) + sc \otimes Levy(\lambda)$,

// $sc = 0.01$ is the amount of the step control and $1 < \lambda \leq 3$

Evaluate $x_{ij}(n)$.

If ($x_{ij}(n+1)$ was superior to $x_{ij}(n)$)

replace $x_{ij}(n)$ by $x_{ij}(n+1)$.

else

Increase the iteration number by 1

End If

End For

// scout bees

For the value $i = 1$ to NS

If (iteration ⩾ MC)

Discard solution, sp_i. This can be employed to get a new solution.

$sp_i = \frac{fitness_i}{\sum_{n=1}^{NS/2} fitness_n}$//where $fitness_i$ is the fitness of food sources.

End If

End For

Record the best solution X_{best} till now, MC = MC + 1.

Through the obtained wo-dimensional entropy threshold for segmentation

Until MC is reached

End.

Assigning the present but optimal value as well as depending on the relationship among the populations, the algorithm improves convergence speed. Adoption of a new fitness assessment and integration with 2D entropy-based multi-threshold segmentation, the proposed modified BCO tests the threshold segmentation.

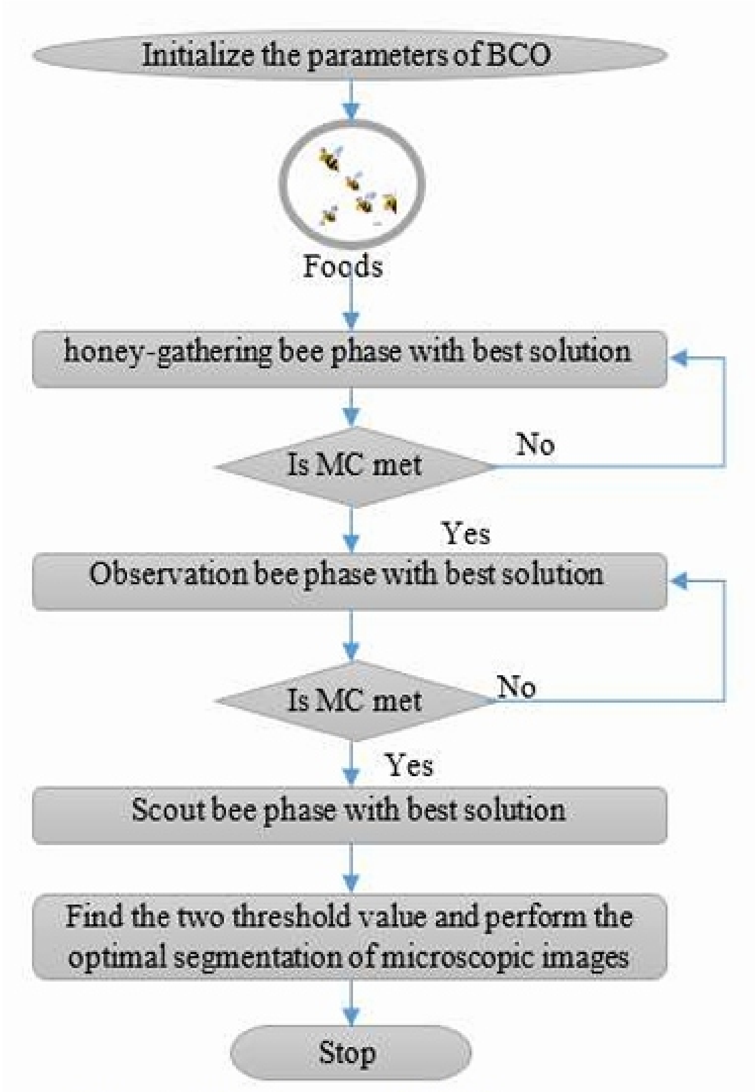

Figure 3: Flow diagram of BCO for segmentation

The feature vector (x_i) of i-th pixel of every image is mentioned as l_i. This is in accordance with the corresponding pixel of the ground truth image, mentioned as [10].

$$x_i = (x_1, \dots, x_k) \quad (6),$$

$$l_i = (l_1, \dots, l_k) \quad (7),$$

The term x_i represents Hue, Saturation, and Value (HSV) of i-th pixel of the image. The value $k = 954486$ indicates the count of pixels in the image. The MCNN model forms the feature vectors (x) along with its labels l . The computed label of the pixel in the image is given rooted in MCNN learning.

3.3 Modified Convolutional Neural Network for Autonomous Robotic Position Control

The proposed work partitions the input data as testing and training sets. During the training phase, the model consumes the already processed images. Whereas in the testing phase, the model evaluates the classifiers by validating them on the testing set. The model labels the image as normal or an attack. In order to develop an MCNN-based intrusion model takes each labeled data into 13×6 size images because each data contains 29 features except the 'Label' feature which is used for image classification. MCNN is primarily construed with RPN along with stochastic max pooling. A more simplified VGG16 is used for feature extraction. The RPN finds if candidate box if the image comprises the target. The primary aim of MCNN is object detection. The structure of MCNN is portrayed in Fig.4.

To extract the feature figure a fundamental feature extraction network is employed that delves HSV features from the image. The VGG16's fully connected layer is eliminated, and stochastic max pooling is chosen to extract the basic features. This version of VGG16 based feature extraction network has convolution along with a stochastic max pooling layer augmented with it. These features cannot be delineated as just primitive features like color and shape. As a matter of fact, the feature law remains unclear. Therefore, isolating the tip along with its types demands much more advanced abstract features. The convolution operations must ensure that overall image features are not overlooked. Also, the network depth must meet the requirements of finding abstract features. Hence, the complete network increases the depth of the underlying network which eventually improves the learning as stacking multiple 3×3 convolution kernels will definitely enhance the efficacy. To combat over-fitting as well as to improve generalization, stochastic max pooling is applied to all pooling layers. The dimensions of the image namely the length and width, are decreased to half after every pooling layer. This results in the formation of smaller yet concentrated and abstract feature images.

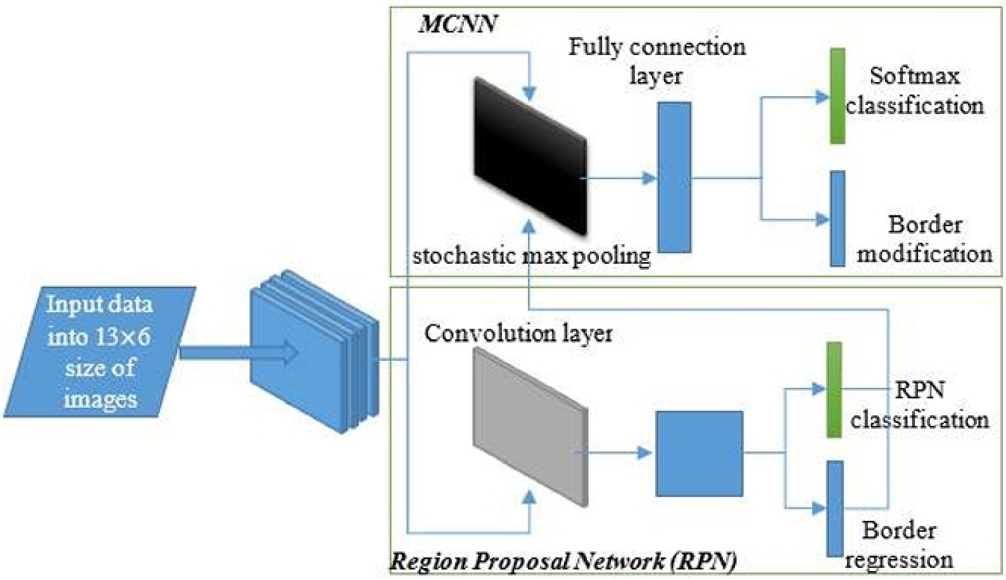

Figure 4: The overall structure of MCNN.

3.3.1 Convolution Layer

In this layer, each neuron is connected to the local receptive field of the previous layer. The local features are obtained by the convolution process. The complete convolution can be given as:

$$x_j^{layer} = f\left(\sum_{i\in RF_j} x_i^{layer-1} \times ker_{ij}^{layer} + bias_j^{layer}\right) \quad (8).$$

The $layer$ indicates the serial number and ker represents the convolutional kernel. The receptive field is represented as $RF_{j.}$

3.3.2 Stochastic Max Pooling

This ranks all receptive field values and randomly selects top-n values. This method is different from the conventional average, max and stochastic pooling strategies. This is actually a combination of max and stochastic pooling. As an initial step define 3 generic pooling strategies. Max pooling, yields the maximum value pertaining to each receptive field and is given as

$$y_{max} = \max(RF) \quad (9),$$

The term y_{max} is pooled maximum value while RF represents the values of the receptive field. The average pooling operates by computing the mean of all values in the receptive field and is given as:

$$y_{avg} = \text{mean}(RF) \quad (10),$$

The value y_{avg} is the outcome of average pooling. Generally, the stochastic pooling chooses a value from the receptive field with some probability (Prb_i) at value (v_i)at position (i) and is given as:

$$Prb_i = \frac{v_i}{\sum_{k\in RF} v_k} \quad (11),$$

The common stochastic pooling is given as:

$$y_{stochastic} = v_l, \text{ where } l \sim Prb(prb_1, \ldots, p_{rbl})\ ) \quad (12),$$

The term $y_{stochastic}$ gives stochastic pooling. Here, the pooling result is chosen from top-n values.

3.3.3 Region Proposal Network (RPN) Model

The input image is transformed into a feature map by subjecting it to the fore-mentioned basic feature extraction network. This feature map is scanned by using a 3 × 3 sliding window. The eigenvector of size 512 will be generated after every scan. This is then sent to fully connected layers. After this, 2k as well as 4k convolution kernels each of size 1 × 1 are employed to perform feature mapping of both classifications as well as regression layers with a step size of 1. This anchor point forms the pivotal sliding window point. Every sliding window forms 9 prediction windows with 3 kinds of size ratios and length: width ratios of 1:1, 1:2 as well as 2:1. The value k indicates the maximum number of prediction windows. Hence k is fixed as 9. These windows must be discarded and then selected. The prediction window that falls beyond the boundary of the image will be discarded. The original label box of input data along with the remaining prediction boxes is used to estimate the ratio of overlapping elements. The prediction box that has an overlap ratio within the range [0.3, 0.7] will be eventually discarded.

3.3.4 MCNN and RPN

The network under study is trained by employing an alternating training method. Since the model has scanty data, it will not be advisable to start the training from the scratch. Therefore, initialization is done using ImageNet parameters. The RPN is trained individually to form a suggestion box. The parameters of this network were adjusted from end to end. The training data is trained by MCNN detection, from which the suggestion boxes are eventually generated by fore mentioned RPN. The MFCNN initializes the RPN based on fixed but shared convolutional layers. The RPN outputs the candidate box that was used earlier used as an input to modify the parameters of MFCNN. The global loss (GL) is estimated as:

$$GL(Prb_i, ap_i) = \frac{1}{N_c}\sum_i GL_c(Prb_i, Prb_i^*) + \lambda\frac{1}{N_r}\sum_i Prb_i^* GL_r(ap_i, ap_i^*) \quad (13).$$

$$GL_c(Prb_i, Prb_i^*) = -\log[Prb_i^* Prb_i + (1 - Prb_i^*)(1 - Prb_i)] \quad (14).$$

$$GL_r(ap_i, ap_i^*) = smooth\ L1(ap_i, ap_i^*) \quad (15).$$

The term i holds an integer value. Prb_i is the likelihood that i-th candidate detection box is rightly predicted to be the target. Also, the Prb_i^* gives an indication value that correlates to i-th candidate detection box. If the same candidate detection is the underlying target object then the value of $Prob_i^*$ is maintained as 1. If the same is a background, then Prb_i^* assumes the value of 0. The term $ap_i = \{apx, apy, apw, aph\}$ gives 4 parameterized coordinate vectors pertaining to the detection box. Whereas ap_i^* $\{apx, apy, apw, aph\}$ represents the coordinate vector of the tipping point that corresponds to the calibration box. The value $GL_c(Prob_i, Prob_i^*)$ refers to the loss during classification while $GL_r(ap_i, ap_i^*)$ is the regression loss. The value N_c expresses the value when the normalized value of the underlying classified item adheres to the min batch. The value N_r is the regression term that is eventually normalized to the count of tip positions, especially in eye surgery robots. The above-mentioned micropipette is advanced autonomously with a finite but constant velocity. This system moves the robot by estimating the distance between the micropipette tip and its corresponding shadow. The robot stops its movement when the estimated distance is less than or equal to a predefined threshold. This threshold can sometimes be roughly zero. This often occurs when the estimation of tip positions of the micropipette is accurate.

3.3.5 The Automatic Tip Position Estimation

The real-time image is processed, to find the tip as well as its shadow by subjecting it to MCNN. The present tip position is transferred to the control PC. This micropipette was managed and controlled to be accurately placed at an already well-defined target in microscopic view through the famous visual serving [23]. Consequently, the robot advances toward the eye ground till the gap between the tips of the micropipette and its corresponding shadow declines below a predefined threshold level. The term ap_{target} in the already defined microscopic image with velocity given as

$$\dot{ap}_{target} = \gamma J^+(ap_{target} - ap_t) \quad (16),$$

The term γ is control gain and ap_{target} is the image feature of the target position obtained from the micropipette. The ap_t is an image feature of the pertaining robotic position. t refers to the timestamp. The so observed micropipette progressed automatically with fixed velocity. The system under study moves the robot. It also calculates the magnitude of the distance between the micropipette tip and its corresponding shadow. The robot stops moving when the distance is less than or equal to an already defined threshold. This threshold can even be roughly zero when high accuracy is reached.

4 Results and Discussion

The experiment to assess the learning data is done with 5-fold cross-validation [10]. Five pairs of images with ground-truth data are used by altering the positions as well as the strength of the light. As a part of the experiment, halogen light is employed for illuminating the micropipette. A customized force sensor is positioned under the eye ground to find the contact of the micropipette's tip. Next, 4 pairs of microscopic images along with the ground truth of Experiment I are employed as learning data for the so-developed MCNN. The target in the image was fixed by selecting the corresponding pixel. The proposed methodology MCNN is compared with the existing method of GMM [10] and Dense CNN [11] with the performance metrics of detection accuracy, recall, f-measure and precision.

4.1 Evaluation Metrics:

The equations of the evaluation metrics are given as:

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FP}} \times 100 \quad (17).$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP+FN}} \times 100 \quad (18)$$

$$\text{F} - \text{measure} = 2 * \left(\frac{\text{recall*precision}}{\text{recall+precision}}\right) \quad (19)$$

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+FP+TN+FN}} \times 100 \quad (20)$$

The term TP indicates True Positive while FP refers to False Positives. The True Negative is indicated as TN whereas False Negative is denoted by FN.

4.2 Precision Rate Comparison

The accuracy of suggested and current models for the number of features in a given database is shown in Fig. 5. While the number of characteristics grows, the corresponding precision also increases. For instance, the MFCNN offers 94% more precision than the GMM and Dense CNN. This is so that the MFCNN can find a relatively better-sorted collection of input within a given period of time without requiring high-dimensional features or derived factors. The proposed method was able to attain improved results since the dataset possesses images with high dimensions. The system can effectively handle as well as enhance the positioning of the tip during eye surgery.

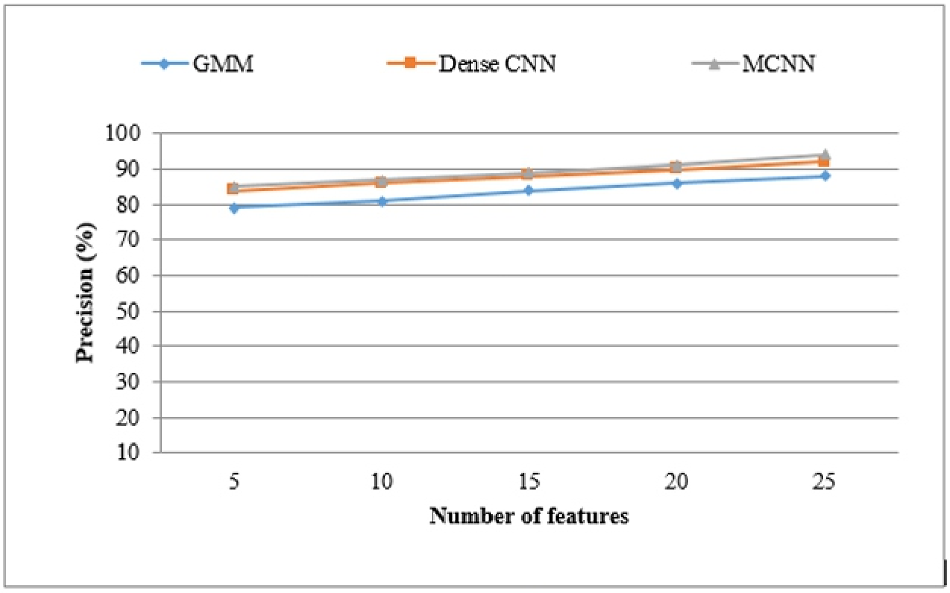

Figure 5: Result of Precision

4.3 Recall Rate Comparison

The recall of proposed and existing models for the number of characteristics in a particular database is shown in Fig. 6. Recall is maximized as the number of features increases. Comparing the MFCNN to the GMM and Dense CNN, for instance, a recall of 92% is achieved. This is due to the fact that the BCO reduces the calculation time of the resulting factors, allowing for the precise segmentation of three regions for subsequent MCNN-based tip position determination. The proposed DL algorithms show supreme results in detecting the tip positions of the underlying eye surgery robot.

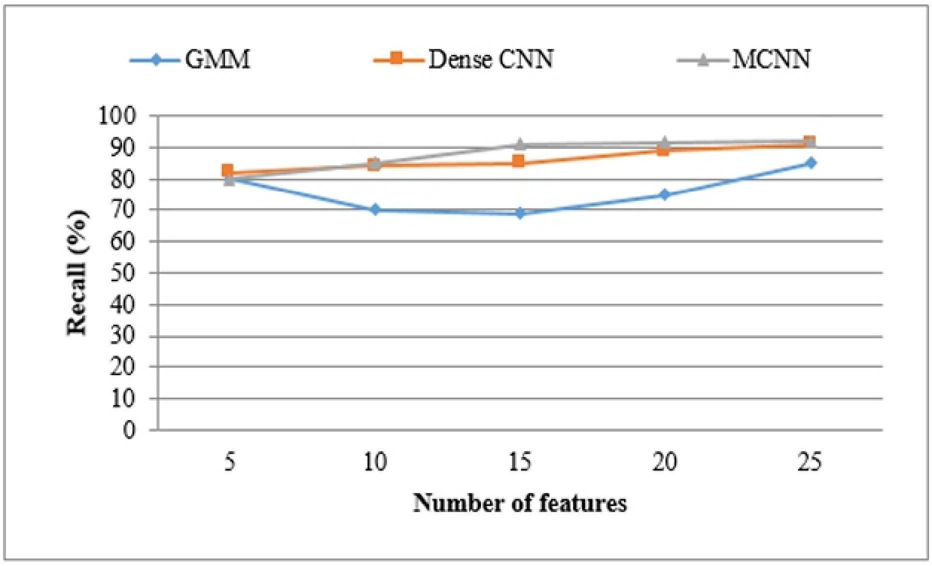

Figure 6: Result of Recall

4.4 F-Measure Rate Comparison

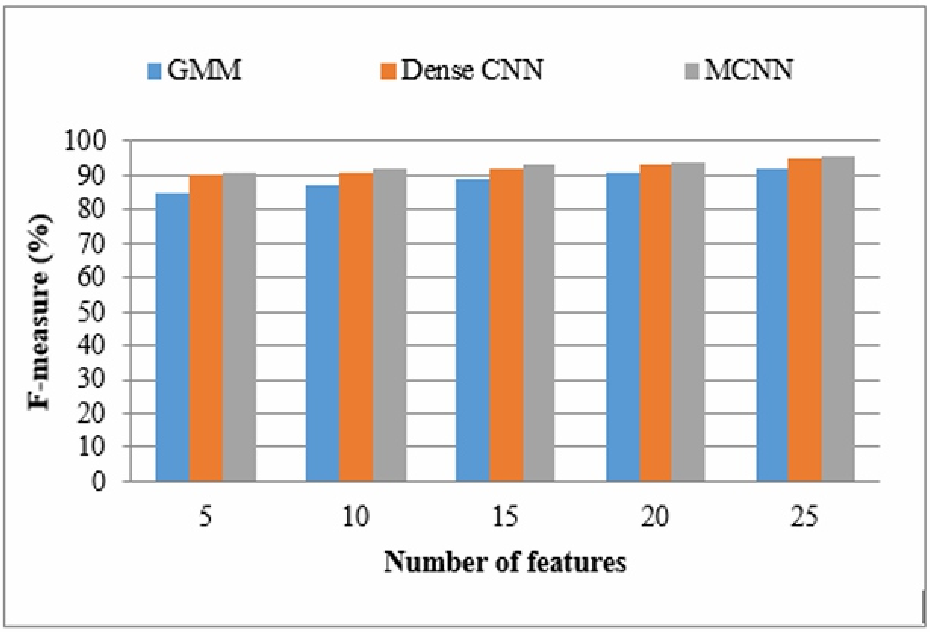

Figure 7: Result of F-measure

The f-measure of proposed and current models for the number of features in a specific database is shown in Fig. 7. The f-measure is maximized while the number of features is maximized. The MFCNN, for instance, has an f-measure of 96% when compared to all other models. EGF algorithm has been applied for eliminating the noise, thus improving image quality. Therefore, the further processing, memory requirement, and time complexity can be reduced by MCNN with the advantage of automatic HSV feature extraction, especially for automatic and autonomous positioning of the robot.

4.5 Accuracy Comparison

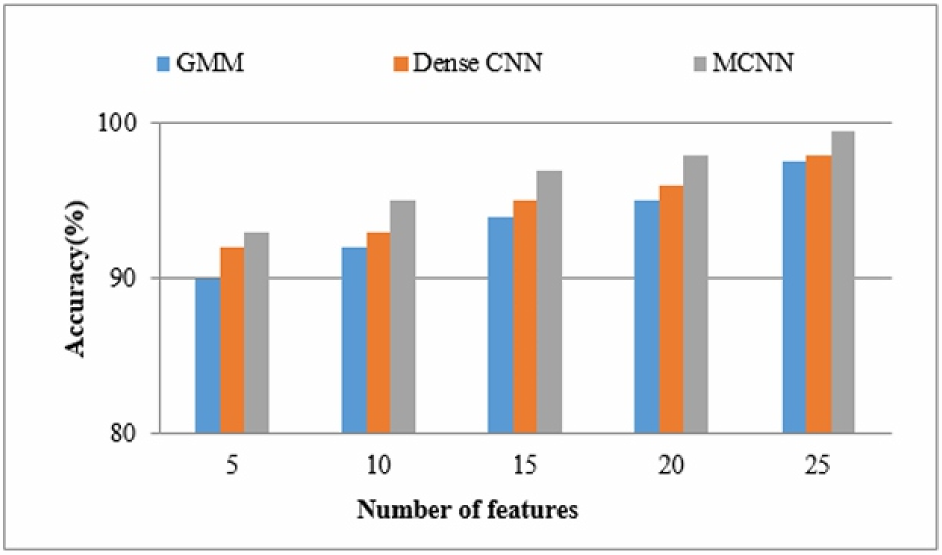

Figure 8: Result of Accuracy

Fig.8 shows the comparison of accuracy between the proposed and existing models. The MFCNN shortens processing time while improving accuracy. Since the MFCNN requires a small number of derived factors during pre-processing, it achieves an accuracy of 99.56% when compared to all other models. The BCO method was considered to segment the three regions with optimal threshold vector and hence the proposed system improved the effectiveness of detecting the position of the tip of the micropipette.

5 Conclusion

The proposed work focuses on the development of safe, reliable and autonomous positioning of the micropipette by exploring its shadow. The scope of this work can be found in the autonomous cannulation of blood vessels in the retina. The experiment pertaining to the proposed work assesses the accuracy as well as the success rate of the autonomous positioning of the micropipette. The success rate of 99.56% is achieved when the micropipette is positioned at a mean height of 1.37 mm. The proposed DL method namely the MCNN aids in the improvement of the position of the tip of micropipette tips and their shadow. Assessing the performance of this method in a clinically realistic environment is also discussed. The nature-inspired BCO-motivated segmentation as well as EFG based pre-processing adds to the accurate detection. Nevertheless, this model has a few limitations like more computation time that serves as a potential future research direction. Construction of DL models for reducing the computational time demands deciding the parameters and hyperparameters. Hyperparameter tuning is one of the attractive research scopes pertaining to the deployment of DL models in predicting the positions of pits.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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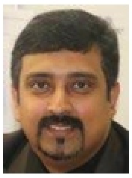

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Space Syntax and Level of Permeability: An Analysis of Giant Interactive Group Corporate Headquarters in Shanghai

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ABSTRACT

This study uses the Giant Interactive Group headquarters as a case study to analyze and understand the spatial configuration in an integrated commercial and hospitality building typology. The spatial layout's effectiveness is obtained by identifying the level of permeability and wayfinding in the case study. The levels are categorized following the five levels of permeability in the Likert scale. The graph is then scrutinized and compiled to highlight the result and discussion. The hierarchical order of space is organized to show the percentage of permeability level present in The Giant Interactive Group headquarters. The study shows how the building achieved a balance in public and private spaces' spatial configuration. The unique spatial structure of the hotel, nature, and commercial office present in the Giant headquarters are blended masterfully into a delicate balance of user and spatial environment. The analysis has shown a different spatial planning method in architecture by using spatial reasoning and justified graphs.

Discipline: Architectural Engineering, Built Environment.

Keywords: Integrated typology; Commercial space, Wayfinding ; Accessibility; Justified Graph; Spatial Study; Spatial configuration; Built environment; Hospitality; Commercial office building.

1 Introduction

In 1984, after publishing The Social Logic of Space by Hillier (1984), architectural theory related to spatial nature had been improving fast. ‘Space syntax’ is a social theory of space and a method of analyzing the areas in buildings and urban environments using an analytical and descriptive tool to represent the spatial formation (Hillier and Hanson, 1984; Hillier, 1996; Dawes and Ostwald, 2018). The analysis also includes graphs to understand and predict user movements (Ratti, 2003). This paper uses space syntax and applies it to achieve the research objective and finally determines how the spaces are configured will relate to the way humans perceive and move through the spatial system (Penn et al. 1998). The research objective is to analyze the flow of spaces or permeability (Ephes, 2006) of the selected case study building.

The case study, Giant Interactive Group Corporate Headquarters designed by Morphosis Architects is a compact village in Shanghai that accommodates diverse programmatic functions in a flexible framework of architectural forms that move into and out of a sculpted landscape. The design gives way to multiple types of users, and each will have a different level of permeability access and wayfinding according to the spatial building formations (Abd Rahaman, 2019). It is the headquarters of modern corporate China to show the limits of capitalist architecture and represent the new generation of China's office building design. Honored with China’s 2013 Green Innovation Award and the 2011 and 2012 Chicago Athenaeum Awards, it is the focal point of many architectural articles that discuss the building’s design.

2 Literature Review

Space syntax is a spatial theory that focuses on space arrangement in building or urban design. It is used as an analysis for space configuration in architectural elements such as buildings or landscapes (Hillier & Hanson, 1984; Hillier, 1996; Zhai & Baran, 2013). According to Nourian et al. (2013), space syntax can be used as a determinant for resolving the connection between social interaction and spatial configuration. Social interaction can be generated by applying space syntax to the built environment spatial arrangement (Ackerson & Straty, 1978; Suryawinata et al., 2017). Measuring accessibility of sustainable transportation using space syntax). Several methods can be used for displaying the result of space syntax analysis such as justified graphs and syntactic steps (Hillier et al., 2016). The graphical representation of the space syntax analysis allows for an easier understanding of permeability and the overall depth of the building's spatial configuration (Natapov et al., 2015). Permeability in this paper refers to accessibility concerning the spatial layout (Farhah, 2019). Permeability and wayfinding are the two measurable factors that space syntax consists of (Yi, 2019). Andrade et al. (2018) discussed permeability between private and public spaces. Erman (2017) analysed architectural space via spatial neighbourhood concept.

According to Nourian et al. (2013), space syntax in architecture identifies the relationship between spatial arrangements with social definitions. However, space syntax is also applicable to all building typologies and cultural buildings. The description related to this paper would be an application of space syntax to generate social interactions by spatial arrangement analysis (Ackerson & Straty, 1978). The case study typology, a commercial office building, is designed to increase social interaction and relieve work stress by using spatial arrangements. Morphosis Architect designed the Giant Interactive Group Headquarters with the concept of "emerging organically from complexity”. The Giant Campus is located in Shanghai, China, and covers a space of 3.2 hectares. The building was completed in 2010 and is home to the Giant Interactive Group, a software development company that creates gaming and entertainment software. The facility separates itself into the east and west sections where the East Campus houses the office complex where most of the company’s work is done. The West Campus comprises a hotel and other entertainment facilities for office workers and hotel guests. The building is private and requires entry towards any part of the building.

Figure 1: View of Giant Campus across the human-made lake on the outskirts of Shanghai, China
(Source: https://www.morphosis.com/architecture/1/)

3 The Giant Interactive Group Headquarters

The Giant Interactive Group headquarters is a complicated complex with a mix of landscaping and office architecture. Located in Songjiang, a reclaimed swampland site, the campus strives to become the center of Songjiang's industrial area. Although currently standing alone, China's development plan has highlighted the area as a new sustainable space with the campus being one of the first to be built.

Table 1: Schedule of accommodation for the ground floor plan

Code	Space of Accommodation	Code	Space of Accommodation
S1, S2, S3 etc.	Staircase	Ms2	Male Shower Room
V1, V2, V3 etc.	Vertical Access	Mc1	Male Changing Room
E1, E2, E3 etc.	Entrance	Gc1, Gc2	Gym Court
Lo1, Lo2, Lo3 etc.	Lobby	Gy1	Gymnasium Room
Ci1, Ci2, Ci3 etc.	Circulation Space	Su1, Su2, Su3 etc.	Hotel Suite
O1, O2, O3 etc.	Office	Mf1, Mf2, Mf3	Multi-Function Space
St1, St2, St3 etc.	Storage Room	Ex1, Ex2	Exhibition Space
M1, M2, M3 etc.	Maintenance Room	Me1, Me2	Media Room
Fw1, Fw2, Fw3	Female Toilet	Op1, Op2	Open Office Space
Fl2	Female Locker Room	Re1, Re2	Reception
Fs2	Female Shower Room	Sec1, Sec2	Security Room

Code	Space of Accommodation	Code	Space of Accommodation
Fc1	Female Changing Room	Gr1, Gr2, Gr3	Garden
Mw1, Mw2, Mw3	Male Toilet	N1, N2	Building System
Ml2	Male Locker Room	Pwr	Power Room
Lr1	Linen Room	Bh1	Back of House

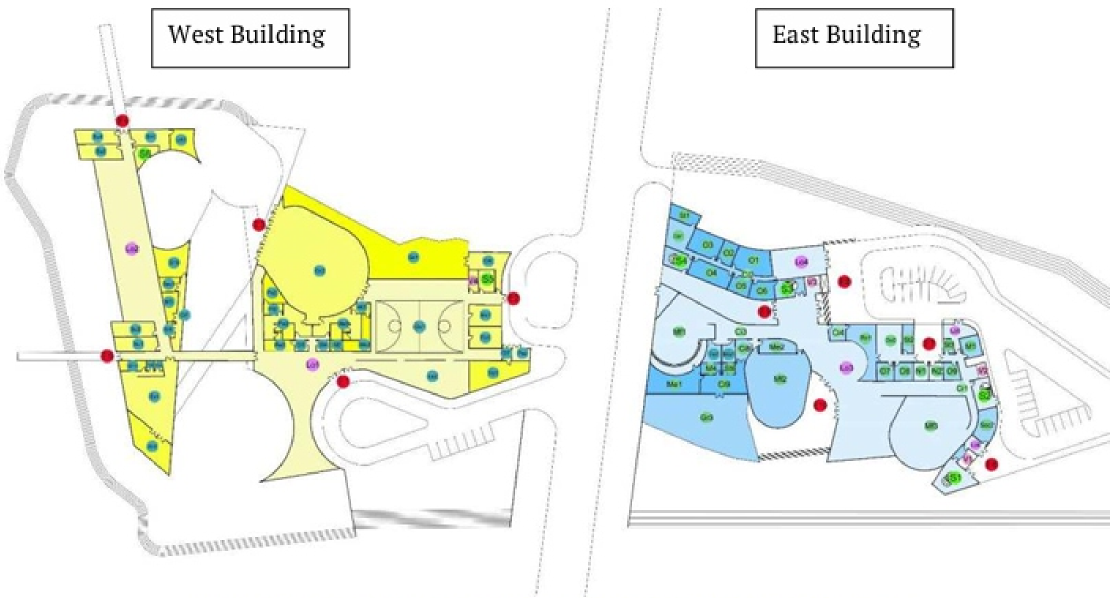

Figure 2: Ground floor plan of Giant Interactive Group Headquarters

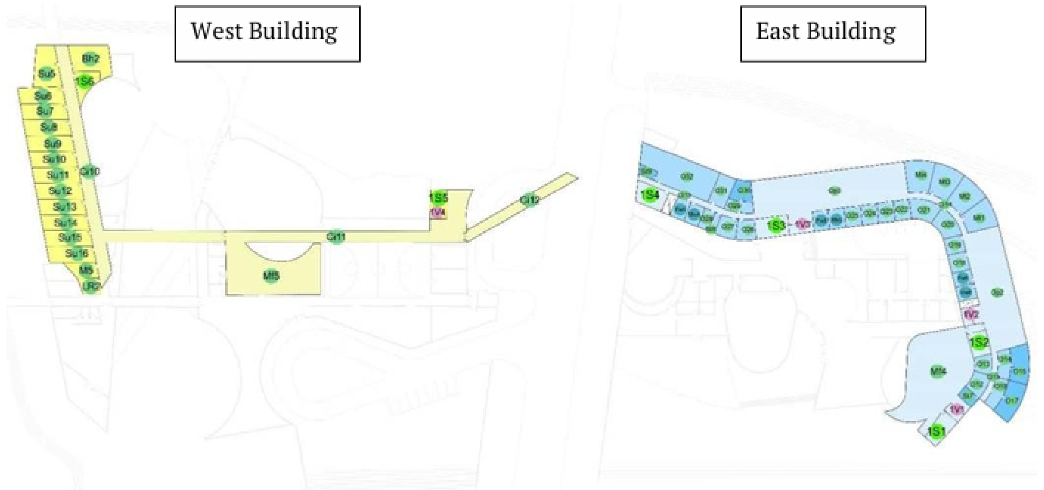

Figure 3: First-floor plan of Giant Interactive Group Headquarters

Table 2: Schedule of accommodation for the first-floor plan

Code	Space of Accommodation	Code	Space of Accommodation
1S1, 1S2, 1S3 etc.	Staircase	St7, St8, St9	Storage Room
1V1, 1V2, 1V3 etc.	Vertical Access	Op2, Op3	Open Office Space
Ci10, Ci11, Ci12 etc.	Circulation Space	Mt1, Mt2, Mt3 etc.	Meeting Room
Mf4, Mf5	Multi-Function Space	Lr2	Linen Room
O12, O13, O14 etc.	Office	Bh2	Back of House
Su5, Su6, Su7 etc.	Hotel Suite		

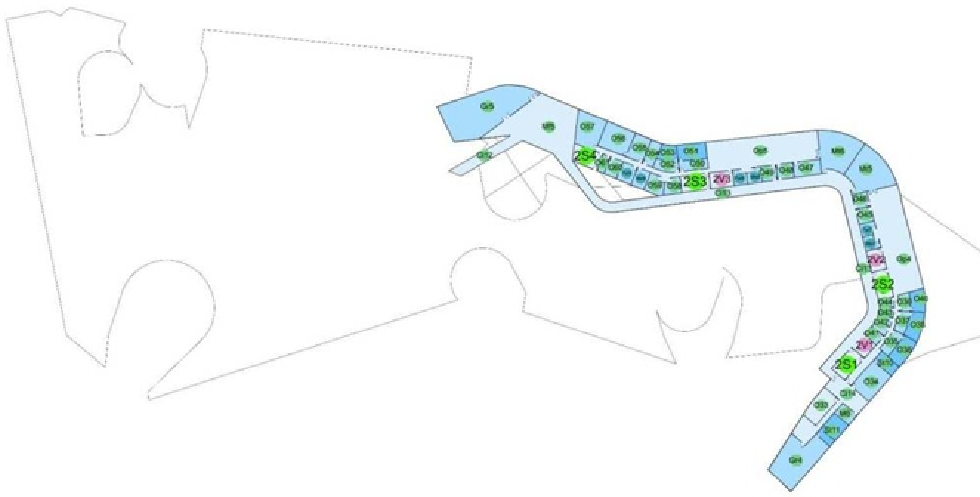

Figure 4: Second-floor plan of Giant Interactive Group Headquarters

Table 3: Schedule of accommodation for the second-floor plan

Code	Space of Accommodation	Code	Space of Accommodation
2S1, 2S2, 2S3 etc.	Staircase	St10, St11	Storage Room
2V1, 2V2, 2V3 etc.	Vertical Access	Op4, Op5	Open Office Space
Ci12, Ci13, Ci14 etc.	Circulation Space	Mt5, Mt6	Meeting Room
Mf6	Multi-Function Space	Gr4	Garden
O33, O34, O35 etc.	Office	Fw7, Fw8, Fw9	Female Toilet
Mw7, Mw8, Mw9	Male Toilet		

In Giant Campus, the building consists of two different wing sections separated by the central Shanghai Highway that connects Songjiang with central Shanghai. This physical environment helps create a territory that defines the level of privacy and access (Mustafa and Hassan, 2010). The east and west division was also highlighted in the building's spatial arrangement. The building has ten entrances in total with five on each wing. Figure 2 shows the west building entrance coded E1, E2, E3, E4 and E5 while the east entrance coded E6, E7, E8, E9 and E10. The west wing opening allows public access up to a certain degree, and the east wing only allows employees access. A walkway connects both wings on the first-floor level.

The office section building's east wing is split into three zones: open, non-hierarchical office space, private offices, and executive suites. Also included within both wings are a library, auditorium, exhibition space, cafe, and conference hall. Large open spaces create visual access visible from different vantage points and help generate a wayfinding guide for visitors (Li and Klippel, 2010). The building also houses various health spaces such as a multi-purpose sports court, fitness space, and jogging track.

Connecting the surrounding environment with the campus are several plazas and gardens that sprout from the landscape. At the south is a pedestrian path that connects to the water's edge, providing access to the lake. The site's circulation and the office building's interior create a wholesome approach used for jogging and scenic walkways. This built form showcases the attention to the environment and establishes a relationship between built form intelligibility and wayfinding performance, which gives birth to an interesting spatial configuration (Peponis et al., 1990).

The campus also boasts maximum energy efficiency and occupancy comfort with minimum heat gain and reduced cooling expenditures. The facade is a double-skin cladding structure, and the glass curtain is insulated to minimize solar heat gain and improve energy efficiency.

4 Research Method

A quantitative survey with space syntax graph illustration is used to determine the level of wayfinding and permeability. The survey data are analyzed through a measurable scale graph (Hassan, 2010). The graph can indicate the level of permeability, which is the paper's main focus. Figure 5 shows the steps of applying labels and constructing a justified graph.

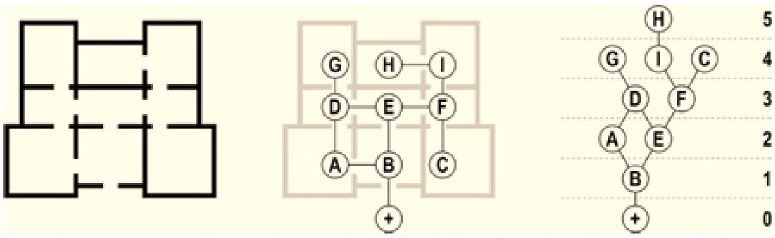

Figure 5: Step-by-step transformation to Justified Graph (after Dawes and Ostwald, 2018).

All plans included in the paper (Figures 2, 3, and 4) are colored to indicate each space's depth level. The plans are also labeled with alphanumeric symbols explained in the included table (Tables 1, 2, and 3) in a group form to analyze the case study (Nasiha, 2019).

Spaces are defined in different categories according to the accessibility of the area to determine the depth of permeability and wayfinding levels. This category is based on the Likert Scale, which is composed of:

1. Public (depth level 0 – 1)
2. Semi-public (depth level 2 - 3)
3. Semi-private (depth level 4 - 5)
4. Private (depth level > 6)

Each user category that corresponds to the spaces will then be arranged in a graph to represent how their permeability flows through the campus. After analyzing each type of user's level, a table of comparison highlights each graph's positive and negative aspects based on the previously done analysis and charts. Wayfinding is defined through the space flow arrangement that guides people through the facility. The result of wayfinding analysis is categorised in four different levels that are based on the Likert Scale, which is composed of:
1. Very Easy
2. Easy
3. Hard
4. Very Hard
Both the permeability and wayfinding levels are finalized in tabular form for further discussion.

Table 4: Likert Scale Framework Example

Code	Depth Scale	Permeability Level	Wayfinding Level	User
		Public	Very Easy	
		Semi-Public	Easy	
		Semi-Private	Hard	
		Private	Very Hard	

5 Result

From this analysis, this research studied the level of permeability and wayfinding divided into respective West Building and East Building. The campus is a space that was divided in its accessibility. The Shanghai Highway splits the building into two different sections that serve other purposes. There are multiple entrances for each facility connected to various areas in the site plan. This building's types of use define the study of permeability level. The users are identified to be as follows:
1. Visitors
2. Staff

5.1 West Building

The West section of the building serves the purpose of relaxing and enjoyable for both the employees and visitors. The building consists of hotel suites and a gym court for various activities. From the ground floor plan in Figure 2, three of the main entrances into the building (E1, E4, and E5) lead the visitors into a lobby area (Lo1 and Lo2) where a reception counter (Re2) will greet them. This path is for visitors who are there for hotel service and exhibition. The other entrances (E2 and E3) lead visitors to the gym area. This path is for visitors who are there for exercising and sports activities. The hotel facilities are complete with 16 suites (Su1 – Su16) and back of (Bh1 and Bh2) for service. An administration (O10) and a security office (Sec1) are also located in between.
For entrances E2 and E3, visitors entered the gym space (Gc1 and Gc2) where facilities such as showers (Ms2 and Fs2) for males and females are prepared. A separate changing room (Fc1 and Mc1) is also nearby for a quick clothes change. On the first floor level (1S5 and 1S6 staircase), visitors can see the environment downstairs through the open spatial arrangement and proceed towards their hotel suites. The upper-level suites have a higher privacy level with multiple spaces as a buffer. The multi-functional space (Mf5) is prepared for visitors to socialize.
A ramp connects the west building with the east building's second-floor level. This ramp is for the staff to access the sports facilities without going out of the building.

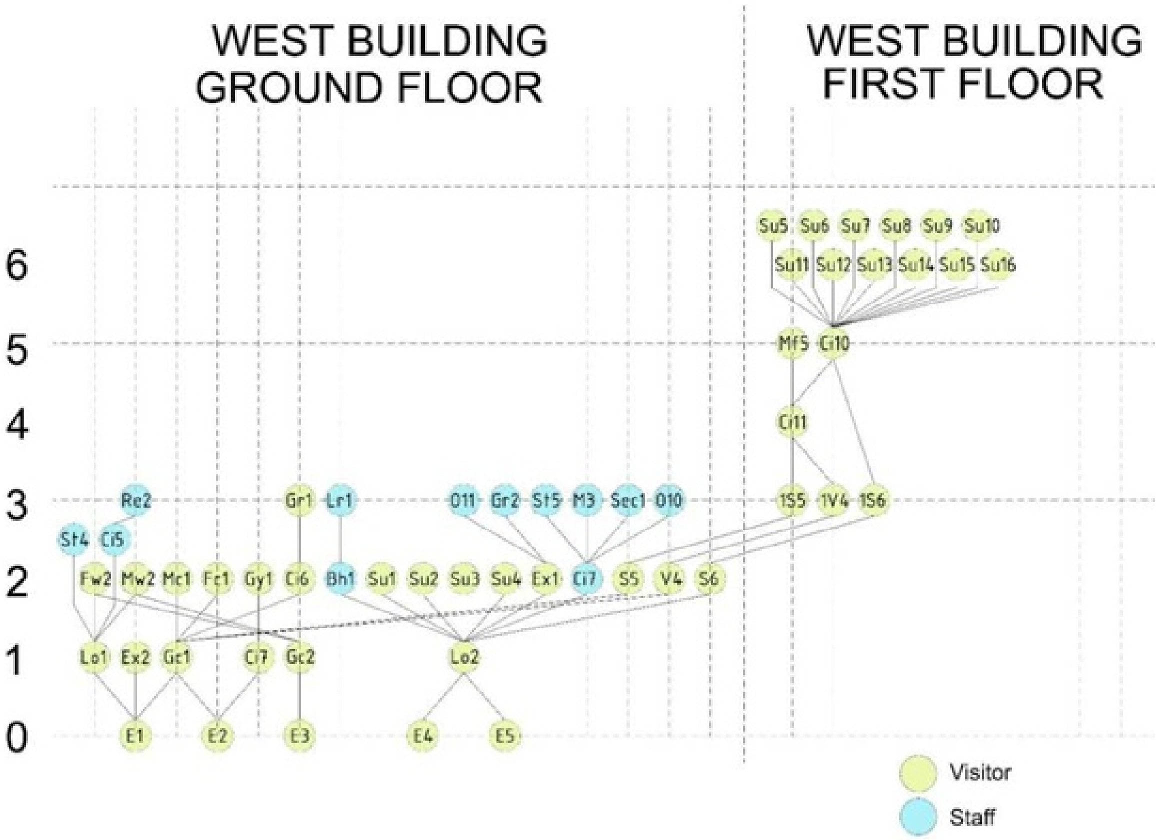

Figure 6: Justified Graph for Giant Interactive Group Headquarters' west building.

From the justified graph in Figure 6 and the floor plans in Figures 2 and 3, we can gather sufficient data to create a Likert Scale framework for further discussion.

Table 5: Likert Scale Framework of the West building

Code	Depth Scale	Permeability Level	Wayfinding Level	User
E1, E2, E3, E4, E5, Lo1, Lo2, Gc1, Gc2, Ex2, Ci7	0 - 1	Public	Very Easy	Visitor and Staff
St4, Ci5, Re2, Fw2, Mw2, Mc1, Fc1, Gy1, Ci6, Gr1, Bh1, Lr1, Su1, Su2, Su3, Su4, Ex1, Ci7, S5, V4, S6, O11, Gr2, St5, M3, Sec1, O10, 1S5, 1V4, 1S6	2 - 3	Semi-Public	Easy	Visitor and Staff
Ci11, Mf5, Ci10	4 - 5	Semi-Private	Hard	Visitor and Staff
Su5 – Su16	>6	Private	Very Hard	Visitor

5.2 East Building

The last section of the facility is mainly for staff usage. The interior environment's spatial design is more closed than the west wing. The building houses multiple office spaces (O1, O2, O3, etc..) and meeting areas (Mt1, Mt2, Mt3, etc..) while also providing spaces for major conventions and press releases. From Figure 2, the building has five entry points with three from the private parking area (E6, E7, and E8), one for emergency exit (E9), and the last one (E10) for pedestrians coming from the south. All entry point leads into a lobby area inside. The E6 entrance is used for employees on the first and second levels for quick access.

From the S1 staircase and V1 lift, staff can immediately access the first-floor multi-function space (Mf4) to go to the office area. The E7 entrance allows access to the building's system and maintenance space. The maintenance staff mainly uses this to access the maintenance office (M1) and the storage area (St2 and St3). The E8 entry point allows access to the ground-level administration office. This office (O1 –

O6) deals with exhibition and gallery reservations. E8 also functions as a drop-off with direct access to the reception desk (Re1) and the three multi-function spaces (Mf1, Mf2, and Mf3). The Mf1 is equipped with multiple spaces (Ci8 and Ci9) to act as a prefunction area and is connected to a private garden (Gr3). The E10 entry point allows access for pedestrians into the spacious lobby.

On the east building's first floor level, the office space is arranged with a circulation path in the middle. This allows office space access to windows and enables maximum space efficiency. Vertical access such as staircases (1S1, 1S2, 1S3, and 1S4) are arranged along the inner side of the building together with the lifts (1V1, 1V2, and 1V3) and bathrooms. Meeting rooms (Mt1, Mt2, Mt3, and Mt4 are located at the best view of the environment. Open office space (Op2 and Op3) is provided for easier interior arrangement in future improvement.

Table 6: Likert Scale Framework of the east building

Code	Depth Scale	Permeability Level	Wayfinding Level	User
E6, E7, E8, E9, E10, Lo3, Lo4, Lo5, N1, N2, Op2, Lo6, V1, S1.	0 - 1	Public	Very Easy	Visitor and Staff
Ci1, Ci3, Ci4, Ci2, O7, O8, St2, Sec2, 1S4, 1S3, 1S2, 1S1, 1V1, 1V2, 1V3, St3, M1, Mf3, Mf1, Mf2, Re1, Me2, Ci8, Mw1, Fw1, O1, O2, O3, O4, O5, O6, Op1, Op3, Mf4, Op2, 2S1, 2S2, 2S3, 2S4, 2V1, 2V2, 2V3.	2 - 3	Semi-Public	Easy	Staff
Ci9, Me1, Ci13, Fw5, Mw5, O25, O24, O23, O22, O19, O18, Ci14, Mw6, Fw6, Ci15, Op5, Ci16, Op4, M4, St6, Gr3, St8, O28, O26, O27, O31, O27, O29, O32, Fw4, Mw4, Mt1, Mt2, Mt3, Mt4, O21, O20, O12, O13, O14, O16, O57, O56, Fw9, Mw9, O54, O52, O59, O50, O58, Fw8, Mw8, O49, O48, O47, Mt6, Ci17, Mt5, St10, O34, O39, O41, O37, O42, O35, O42, O45, O44, O46, Fw7, Mw7.	4 - 5	Semi-Private	Hard	Staff
O30, St9, St7, O15, O17, O53, O51, O33, Gr4, M6, Gr5, O40, O38, O36.	>6	Private	Very Hard	Staff

The second floor of the east building shows a different spatial arrangement. The main circulation area (Ci16) that connects the building is located on the inner side rather than the center. This arrangement allows for quick and easy access to the ramp that connects the east and west wings. A roof garden is also placed at the building's ends for the staff to relax.

From the justified graph in Figure 7 and the floor plans in Figures 2, 3, and 4, we can gather sufficient data to create a Likert Scale framework for further discussion.

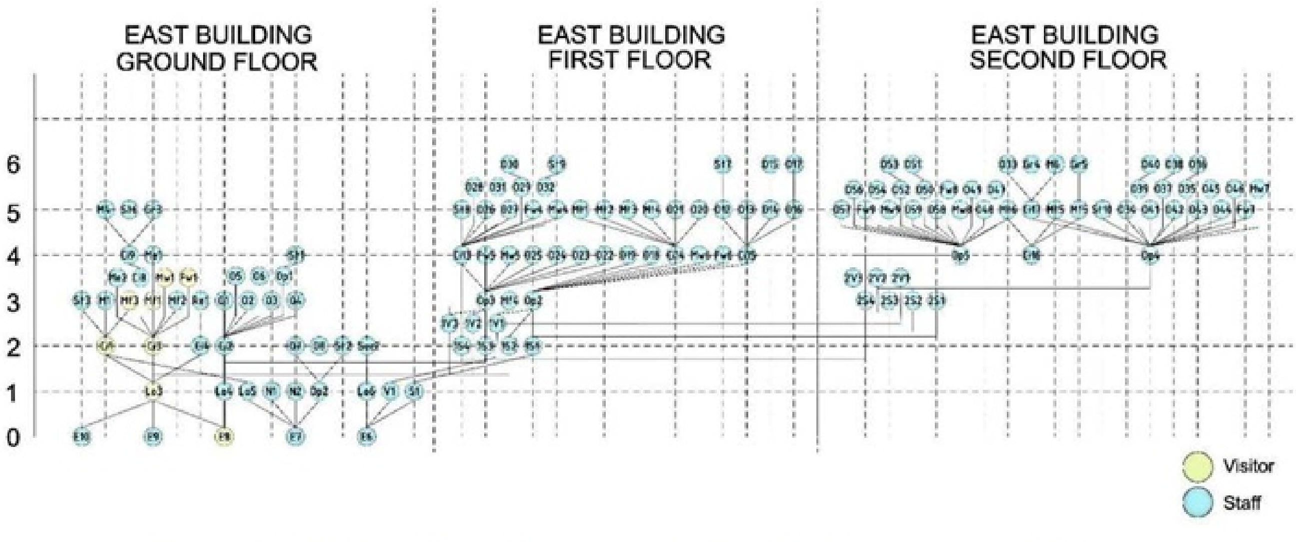

Figure 7: Justified Graph for Giant Interactive Group Headquarters' east building.

6 Discussion

From the research's overall result, the justified graph obtained was in the shape of a shallow tree model. The spatial relations shown in Figures 6, and 7 highlight the immediate branching of space starting from depth level 1. The building offers a complex spatial arrangement on the upper floor where the east and west buildings are connected. To understand the overall building's spatial configuration, the spatial order of all related spaces needs to be considered (Onur, 2017). The compiled results from Tables 5 and 6 are combined to create the following Table 7.

Table 7: Likert Scale Results

Level	% of permeability % of wayfinding
Public / Very easy	12.75
Semi-Public / Easy	36.75
Semi-Private / Hard	37.75
Private / Very Hard	12.75

The result shows that the building is mainly a semi-private / semi-public structure with a difference of 1%. The designer has exhibited a great example of how a hospitality typology is combined with a commercial office building. The balance between the two is maintained and can be seen in the justified graph result.

The building's permeability level is at a medium level where the most private area is located at depth level 6 (CEO and manager's office). Other spaces are scattered at an acceptable level of permeability. The permeability level is very high at the west building, with 54% at the Semi-Public level, and easy to navigate. The west building permeability level is quite low, with 50.3% at Semiprivate and hard to navigate due to the long winding access area design. For a private office, such a level of privacy is acceptable.

The overall building has a high number of end rooms due to its design nature. A total of 58.6% of the total spaces consist of end rooms. The building also consists of 10.2% of spaces with more than three branching connections. The busiest space is the open office area (Op4 and Op5) with more than ten connecting spaces. The total % for the staircase compared to the overall building space is 0.1% while lifts are at 0.08%.

7 Conclusion

The Giant Interactive Group headquarters is a building that challenges the nature of building typology by successfully integrating hotel, office, sports, and nature together. From the analysis, it can be concluded that the headquarters' spatial design is carefully thought out to ensure balance in permeability and wayfinding. The decision to integrate the building's natural environment shows the designer understood an integral part of wayfinding (Farr et al., 2012). The bold and innovative interior design and color choices also influence visitors to identify space. Such visual feedback can reduce pedestrian's uncertainty and anxiety, even with the curve and winding plan layout (Vaez et al., 2019). This strengthens the visual connection between the user and the environment and allows for better spatial memory to navigate the space. The open layout on the ground level also allows users to cross through spaces easily without memorizing pathing. The simple office arrangement also functions well to maximize space efficiency and simplify the overall building layout. Although the paper is limited to online sources for the case study, a comprehensive study in space syntax analysis was achieved.

8 Availability of Data and Material

All used or generated data from this study is included in this article.

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Recent Trends in Precision Agriculture: Applications & Challenges in Precision Farming

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ABSTRACT

Agricultural products for food production are expected to increase by 70% in 2050 to cater for the rising population. However, conventional agriculture (CA) practices cause unpredictable production, resource overutilisation, and unregulated waste production, while affecting climate change through greenhouse gas emissions. Precision agriculture (PA) is one of the fastest-growing agriculture technologies. PA strives to improve agricultural productivity, land-use efficiency, production costs, environmental quality, and food supply sustainability. Despite expanding research on new technology adoption, PA continues to suffer from a lack of agreement on its conceptualisation. Thus, this study examined agricultural developments from the conventional era to the current PA trends, with a focus on precision farming. This initiative would assist farm managers and agriculture analysts in identifying PA implementations and current PA technology for adoption while providing decision-making support.
Discipline: Agriculture & Information Technology; Spatial Technology.

Keywords: Precision farming; Agricultural machinery; IoT; GIS; Agricultural engineering; PA trend; PA technology; Automation; Conventional agriculture.

1 Introduction

Concerns about food security have long plagued many developed and emerging economies worldwide. The deterioration of crop yield essentially affects food security. Factors such as population growth, decreasing arable land for crop production, water scarcity, climate conditions,and a declining or aging farmer population have worsened this issue [1]. Enormous demand for food production must be served cost-effectively without wasting resources such as water and electricity. The world's population is projected to be 34% larger than the year 2020, which may hit 9.6 billion people by 2050 [2]. The demand for agricultural products for food production is expected to increase by 70% in the same year to cater to the rising population [3]. At the same time, the agricultural sector must address severe challenges due to conventional farming practices that lead to erratic production, overuse of resources, and unrestrained waste production [4]. Precision agriculture (PA) is a recent advancement that addresses these challenges through farm management approaches to optimise yield productivity.

In [5],[6], [16]-[18], PA has been proven to have significantly improved conventional agriculture (CA) practice and consequently improved crop yield. However, a variety of stressors, including rapid population growth, natural resource depletion, environmental pollution, crop diseases and climate change, pose increasing threats to the global agricultural sector that need to be addressed in PA. The Internet of Things (IoT) and advanced machinery are among the most common technologies adopted for effective farming. A need also arises to integrate the current PA practice with the use of cutting-edge technology, such as artificial intelligence (AI). Table 1 summarises the recent reviews in the field of PA based on their agricultural application areas. Despite the abundance of literature on this subject, this research highlights the theoretical gaps in other advanced engineering concepts that can be integrated with the current PA practice. A review of PA technologies is presented and thus provides insights for other researchers to utilise the information in the PA sector.

Table 1: Summary of recent PA reviews.

Author	Year	Area	Research Focus	Research Gaps
Chin et al. [9]	2023	Traceability	The automation of plant disease detection using drones. Presented an identification of common diseases, pathogens, crop types, drone categories, stakeholders, machine learning (ML) tasks, data, techniques to support decision-making, agricultural product types, and challenges of drone-based plant disease identification in literature.	Decision support system for plant disease detection. Drone/unmanned aerial vehicle (UAV) communication technologies.
Shin et al. [10]	2022	Traceability	Machine vision-based automation in detecting stress and diseases on crops, leaves, fruits, and vegetables.	Real-time detection. Decision support system for machine vision-based automation. Cellular communication technologies
Corwin et al. [5]	2019	Traceability	Monitoring tool to address soil spatial variability mapping. Also presented a characterisation of spatial variability of soil salinity using georeferenced soil electrical conductivity (ECa).	Machinery coordination. Decision support system for crop sampling and monitoring and disease inspection.
Mavridou et al. [11]	2019	Traceability	Machine vision applications in PA, support fruit grading, fruit counting, yield estimation, and plant health monitoring. Also, focus on machinery coordination and agricultural harvesting robots.	Communication technologies Drone/UAV applications
Rivera et al. [12]	2023	Information-driven crop production	Reviewed light detection and ranging (LiDAR) technologies for crop cultivation. Categorized LiDAR applications into crop-related metric estimation, tree and plant digitisation, vision systems for object detection and navigation, and planning and decision support.	Cellular wireless communication technologies such as 3G, 4G Long-term Evolution (LTE) and 5G.
Verma et al. [13]	2020	Information-driven crop production	Multimedia data collection and decision-making ability approach in PA with IoT sensors along with wireless communication technologies.	Wireless sensor network (WSN). Cellular wireless communication technologies such as 3G, 4G LTE and 5G.
Thakur et al. [7]	2019	Information-driven crop production	WSN technologies adopted for PA as well as available sensors and communication technologies.	Cellular wireless communication technologies such as 3G, 4G LTE and 5G
Méndez-Vázquez et al. [14]	2019	Site-specific farming	Pest detection management control using site-specific zoning techniques. An unmanned aerial system (UAS) is used to capture georeferenced data using high-resolution multispectral images.	Site-specific monitoring (nutrients and diseases). Site-specific spraying (herbicides, pesticides, fertiliser). Site-specific irrigation. Hyperspectral imaging.
Norhashim et al. [15]	2023	Field robotics	UAV for PA in Malaysia based on technical requirements (weight, wing span, wing loading, range, maximum altitude, speed, durability, and engine type), as well as sensors and data processing methods. Applications of UAVs are mostly for weed mapping, crop growth and health monitoring, crop production estimation, and crop spraying.	Combination of several advanced machineries for robust and efficient robotic systems. Cellular wireless communication technologies such as 3G, 4G LTE and 5G.
Gonzalez-De-Santos et al. [8]	2020	Field robotics	Advanced machinery with the utilisation of different types of sensors for specific purposes. Translation of automated factory concept into automated farm utilizing advance machinery.	Mobile robots such as UAVs and UAS
Saiful et al. [6]	2020	Field robotics	Specific advanced machinery of robotics and vehicles to execute specific agricultural operations (planting, inspection, spraying, and harvesting) according to its limitation capabilities	Combination of several advanced machineries for robust and efficient robotic systems. UAV for monitoring, spraying, seeding, etc.
Martin et al. [16]	2020	Fleet management	Field operations in agriculture, focusing on the optimization of agricultural machinery's movement in sugarcane production. Approaches based on spatial division configuration, route planning, and cost parameters (fuel and time consumption) were presented.	Cellular wireless communication technologies such as 3G, 4G LTE and 5G. Real-time vehicle, machinery detection and coordination and operational information.

PA applications have proven successful in diverse agricultural sub-branches, including precision horticulture (PH), precision farming (PF), precision livestock farming (PLF), and precision viticulture (PV). These sub-branches are illustrated in Figure 1. PH is a production management approach in which precise inputs and practices are implemented at precise locations within an orchard or particular sites with the intention of ‘doing the right thing’, ‘at the right time’ and ‘in the right way’ [17]. PH normally involves the cultivation, processing, and marketing of fruits, vegetables, flowers, medicinal, aromatic, and ornamental plants [18]. PLF is described as the implementation of process engineering principles and methods in livestock farming to automatically monitor, model, and manage animal production. PLF also involves the conversion of bio-responses into pertinent information that can be easily applied to various management aspects focusing on both animals and the environment [19]. PLF tools are designed to be a completely automated management system that provides reliable data and warnings based on continuous animal monitoring [20]. Meanwhile, PV refers to the method of using site-specific techniques in vineyard production to enhance grape quality and yield while reducing negative environmental impact [21]. PV focuses on maximising the oenological potential vineyards, particularly in regions where high-quality wine production standards are enforced [22].

In this research, PF is the main focus in which this article reviewed the recent trends and challenges in PF. PF is practiced in both small and large farms, implying a management strategy to increase productivity and economic returns while minimising the environmental impact [23]. The rapid development of recent technological advancements in information and communication technology (ICT) and geographic science provides tremendous opportunities for the development of optimised distributed information systems for PF. This strategy will ensure their ability to meet the nation’s food security needs in the face of diminishing natural resources, particularly land and water. Applications of PF can be further classified into five sectors, including traceability, information-driven crop production, site-specific farming, field robotics, and fleet management [24]. Thus, this research aimed to gather the existing knowledge on technologies used in the PF sector, categorised based on the five sectors, and to review the existing PA technologies implemented from early techniques to their current agricultural practices.

This paper is structured as follows. Sections 2 and 3 thoroughly describe the CA and PA from the PF perspective, respectively. Section 4 discussed the state-of-the-art of PA technologies in PF. Further recommendations and practical considerations are also provided. Finally, Section 5 presented the review conclusion. Table 2 lists the acronyms used in the paper.

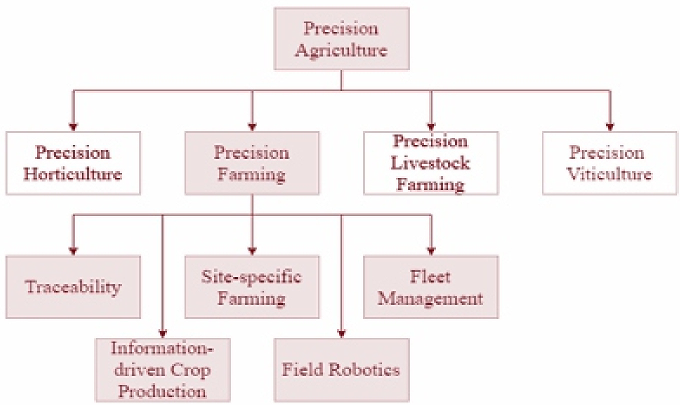

Figure 1: Precision agriculture categorization [24].

Table 2: Definitions of acronyms and notations.

Acronym	Definition	Acronym	Definition
AI	Artificial intelligence	PLF	Precision livestock farming
CA	Conventional agriculture	POI	Points of Interest
DL	Deep learning	PV	Precision viticulture
GIS	Geographic information system	SSDC	Site-specific disease control
GPS	Global positioning systems	SSNM	Site-specific nutrient management
ICT	Information and Communication Technologies	SSWM	Site-specific weed management
IoT	Internet of Things	UAV	Unmanned aerial vehicle
ML	Machine learning	VRA	Variable rate application
PA	Precision agriculture	VRT	Variable rate technology
PF	Precision farming	WSN	Wireless sensor network
PH	Precision horticulture		

2 Literature Review

2.1 CA Background

Studies on the origins of farming history can be traced back to the 1930s through archaeological excavations and investigations. The study by Tauger [25] showed that early humans in the Neolithic Revolution developed agriculture approximately 10,000 years ago in response to a seasonal climate following the end of the last ice age. Agriculture has played an important role in the advancement of human civilisation. Even though early farming techniques were influenced by local climate conditions, most farmers continued to plant on the same field year after year until the soil nutrients were depleted. Agricultural techniques such as irrigating, intercropping, and crop rotation have improved farming productivity over time. It is a primitive form of agriculture that heavily relies on local cultures, instruments, natural resources, organic fertiliser, and the farmers' cultural practices [26]. North Africa, East Africa, and West Africa are amongst the poorest countries in the world, with subsistence and small-scale traditional agriculture remaining the mainstays of their economies [27]. However, farming has changed dramatically over the last few centuries, and many countries have shifted towards CA practices [28].

CA is the most common form of agriculture, where farmers typically utilise synthetic chemical inputs that include fertilisers, pesticides, herbicides, and other continuous inputs. CA techniques were developed in the late 19th century but were not widespread until after the Second World War [29]. However, half of the world's population notably continues to practice CA [26]. In countries that practice CA, synthetic chemical resource inputs are handled uniformly across fields, ignoring the naturally occurring spatial variability of soil and crop conditions between and within fields [5]. Consequently, CA is usually resource and energy-intensive.

2.2 CA Issues

CA adopts tedious manual crop inspections, whereby human experts constantly monitor crops to detect diseases early and prevent them from spreading. However, farmers with hectares of land experience difficulty reaching every nook and cranny of a crop for regular inspection [30]. Additionally, these manual assessments can be time-consuming and cost-intensive [31].

The presumption of soil nutrient classification in CA is that a sampling point indicates the status of the specified region and that variances within it are distributed randomly [1]. However, intensive laboratory testing for soil nutrients such as nitrogen, phosphorous, and potassium is time-consuming [32]. The collection of a huge number of soil samples involves the laborious task of gathering soil chemicals and requires expert laboratory operators, increasing cost and time. These limitations led to undersampling, which renders it inaccurate for the estimation of soil fertility in large crop areas.

Currently, 70% of the global water consumed is used for crop irrigation [31]. However, a water management control system that allows continuous flooding of water to provide the best growth environment for crops (e.g. rice), is seriously lacking [33]. In addition, risks of groundwater contamination and other environmental threats exist as a result of the excessive usage of herbicides, fertilisers, and pesticides in agriculture.

Herbicides are substances used to keep the growth of unwanted plants at bay. Application of herbicides in CA is the most common practice of weed control. However, farmers tend to spray the same amount of herbicides over the entire crop, even in weed-free areas. Overuse of herbicides will eventually result in the mutation of weeds into herbicide-resistant ones. These weeds will with crops for available resources such as water and space, causing losses to crop yields and their growth [31].

In addition, insufficient blanket spreading of fertiliser without discrimination and reference to the plant's condition, as well as available soil nutrient content, can damage crop growth. It will ultimately result in inconsistent fertiliser distribution, either undersupplying needed nutrients to the plants, which will negatively impact plant development or oversupplying it, which will increase input costs and create negative environmental consequences [1].

Conventional crop spraying utilises manual air-pressure and battery-powered knapsack sprayers, which may lead to major pesticide losses. This insufficient method of pesticide crop spraying is not only time-consuming but can also lead to untimely spraying [31]. Besides that, the dependency on manpower methods causes inefficient labor costs.

In a nutshell, CA adopts tedious manual crop inspection and soil nutrient sampling that results in either under-sampling or over-sampling. Moreover, the blanket spraying method can cause groundwater contamination. Legitimate concerns about the adverse environmental impact and production output from the use of CA methods should therefore be addressed. As such, CA practices are being actively transformed by adopting PA, a more precise and reliable approach to collecting, storing, restoring, and analysing field data.

3 Precision Agriculture in Farming

3.1 PA Background

A wide range of stressors pose increasing challenges to the global agricultural sector, including a rising population, resource depletion, pollution, crop diseases, and climate change. PA is a viable approach for addressing these issues with the adoption of variable rate application (VRA) into farming activities [34]. VRA is an aspect of PA that automates the application of materials such as fertilisers, chemical sprays, and seeds to the land. The application of these materials is determined through precise data collection from on-field sensors, maps, and GPS that identify and monitor the characteristics of a specific area of land [35].

3.2 PA Application and Technologies

VRA in PA can be further classified into five agriculture applications, including traceability, information-driven crop production, site-specific farming, field robotics, and fleet management. The following subsections briefly explain these applications. Meanwhile, the summary of these application technologies is tabulated in Table 3.

3.2.1 Traceability

In agriculture, traceability refers to all stages of data collection, classification, conservation, and implementation related to relevant processes in the food supply chain. Its purpose is to provide assurance to customers and other stakeholders on the origin, location, and background of the product, as well as to be used in crisis management in the event of food quality and safety concerns [36]. Accordingly, product tracking and traceability, especially for on-farm operations, have emerged as one of the most crucial matters in PA research. The use of a Geographic Information System (GIS) as a PA tool will provide facilities for improving traceability information by linking it to agro-environmental situations, including soil quality, crop productivity, pest control, disease control, and local properties [36].

An example of a GIS application can be found in [37], through the web application Web Paddy GIS. This web-based application decision support system (DSS) is capable of storing, managing, analysing, and visualising all information on a single platform. The architecture of Paddy GIS was developed by using free and open-source software. Therefore, the platform may be remotely accessed by users using their smart phones. The data stored on the database contains agricultural information, plot location information, and information on pests and diseases.

Lamanna et al. [38] presented a study on nuclear magnetic resonance profiling based on GIS data to evaluate the spatial variability of metabolic expression in durum wheat fields in Italy. The presented solution is used to adapt agronomic practices for providing water and nutrients to areas depending on the metabolic expression of durum wheat at three different vegetation stages.

The use of Global Positioning Systems (GPS) on agricultural machinery provides location and time information for all treatments. Given that the use of GPS-enabled smartphones has become increasingly common, farmers can maximise it in the field by taking images of suspected pests or diseases and sending them to the internet cloud. With the GPS coordinates of the spot where the picture was taken, the potential desirable treatment will then be computed in the cloud system based on crop information such as type of crop, planting date, and expected harvest date. These pieces of information are initially stored in the cloud [39].

Abu Bakar and Bujang [1] reviewed how the integration of GPS-enabled mapping devices with sensors helps identify and analyse sampling sites by using these geo-statistical tools. Satellite images or aerial photography may be used to perform GPS mapping functions. Apart from using GPS-based devices for crop sampling, GPS data can also be applied to shipping documents so that the product's origin (region, farmer, field) can be tracked and the buyer can be assured of the veracity of the origin claims [39].

3.2.2 Information-Driven Crop Production

Crops have initially been managed in CA under the presumption of standard soil, nutrient, moisture, weed, and insect conditions. The application of chemicals, irrigating, fertilizing, and performing such treatments have all been over- or under-applied due to uniform and untargeted application. However, advances in crop growth modeling, as well as in the use of software for monitoring and collecting data from farms, have opened the way for a new field of insights to aid PA decision-making [1]. The advent of GPS and Global Navigation Satellite Systems (GNSS) has enabled the practice of PA, which employs information technology to bring data from multiple sources to crop production decisions. The fundamental pieces of knowledge required to identify the geographic position of phenomena are critical. This is because the geographical and temporal variability of soil and crop variables between and within fields is the factual basis for PA. The purpose of georeferenced data collection is to provide accurate information about the spatial and temporal variability of crops to facilitate the best decision-making by PA to increase yield production [2].

Sensors and automation are vital applications in the agricultural sector. An example of its usage is to track the health and performance of the farm [40]. The adoption of remote sensing in agriculture has resulted in the systematic collection of data across vast geographical areas [2]. Remote-sensing applications in agriculture refer to non-contact measurements of electromagnetic radiation that interact with soil or plant content. The application of remote sensing focuses on a wide range of endeavors, including crop yield, crop nutrients, water tension, plant disease infestations, and soil properties such as

organic matter, moisture, clay content, pH value, and salinity [41]. The platforms for making these measurements often use satellites, aircraft, tractors, and hand-held sensors. However, cloud cover also severely limits the availability of remote-sensing imagery from satellite and airborne platforms, whereas ground-based remote sensing is less affected by this constraint. Additionally, higher spatial and spectral resolution remote sensing data are often prohibitively expensive [41].
Ismail et al. [42] proposed an IoT-based paddy monitoring and advisory system called e-Padi, as shown in Figure 2. By using microcontrollers to control the wireless network and sensor nodes on an IoT-enabled platform, the prototype offered continuous monitoring of the paddy field area as well as warning and advisory reports. All collected data from the sensor nodes will be stored in a database management system, allowing users access to it via tablets, smartphones, or computers. The techniques from this research are frequently implemented in PA to increase crop productivity through real-time monitoring of crop environment parameters. Besides, with the implementation of PA, the dependency on manpower is reduced and costs are efficiently utilised.

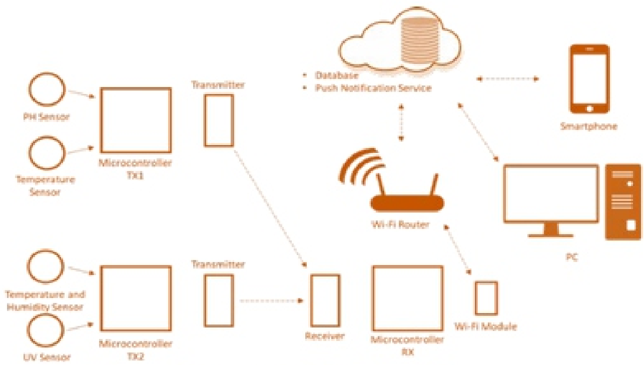

Figure 2: The e-PADI System [42].

Sharma et al. [43] presented a fuzzy logic-based identification algorithm for determining a suitable cropping window and minimum pest growth based on data collected from a wireless IoTenabled sensor network deployed in medium-grass vegetation, such as rice and sugarcane crops. The experiments were conducted in an agricultural field in Madhya Pradesh, India, in which the deployed IoT sensors collected moisture, rainfall, and temperature data for the area. The solution aimed to help farmers identify appropriate planting seasons through IoT applications, as well as prevent pest development and take proactive precautions to achieve maximum crop yields.

3.2.3 Site-Specific Farming

Site-specific farming is the practice of managing specific areas within fields rather than the entire field. The management procedure is to identify and quantify variations between the fields, document these differences at particular sites, and use this information to handle improvements in management or inputs [44]. In other words, site-specific farming is the act of doing the right thing, at the right time and at the right places. Site-specific farming uses numerous methods for managing resources, including water, herbicides, fertilisers, and pesticides.
Site-specific weed management (SSWM), presented in [31], refers to the spatially variable rather than uniform application of herbicides over the entire region. Selective herbicides eradicate particular weed species while causing minimal damage to the target crop. In this sense, the sector is divided into management areas, each of which is assigned a unique management strategy. This process, in turn, will reduce the total crop inputs, and herbicides will be applied in a more targeted manner. This scenario is ideal because weeds usually spread only across a few areas of the field, applying uniform management is thus a waste of herbicides.
Another SSWM approach was presented by Li et al. [45], who proposed a smart weed-control system

that utilised a real-time sensing system for the automatic localisation and recognition of vegetable plants. In particular, the authors developed a system that accurately distinguishes vegetable plants, such as tomato and pak choy, from weeds in a real-time manner by using an integrated sensing system consisting of camera and color mark sensors. Through real-time identification, an effective weed eradication method can be performed.

Conventional fertiliser applications conducted by farmers may not meet the crop requirements and are not resource-efficient. Farmers often inefficiently apply fertilizers with regard to the amount and type of fertiliser at a particular stage of crop development. Thus, an appropriate nutrient management strategy could help boost the low recovery efficiency of fertilizer that results from excessive usage. Site-Specific Nutrient Management (SSNM) was developed as an integrated nutrient management strategy through a web application decision-support software called Rice Crop Manager (RCM), presented in [46]. The quantitative relationship between nutrient supply and crop demand, which differ enormously in space and time, was considered. SSNM serves to recommend the application of an acceptable amount of fertilizer to the rice crop at the appropriate growth stage through RCM. The SSNM was studied in irrigated ecosystems and demonstrated a substantial improvement in rice yield throughout Asia.

Precise nutrient administration may be enabled by quantifying the site-specific nutritional status of the soil [1]. The objective is to create an on-site model by using aerial images to map out the plantation areas for nutrient distribution. The aerial images provide an accurate determination of spatial variability, allowing for the identification and analysis of subsequent sampling sites. The nutrient distribution model for the particular sampling sites will then be obtained by utilising geostatistical tools. With this method, the soil preparation process can be sped up by removing the need for time-consuming manual sampling and labor-intensive laboratory research.

Crop health is a critical consideration requiring monitoring, as crop diseases may result in substantial economic losses due to decreased yield and quality. Crops should be monitored continuously to identify pathogens early and prevent them from spreading, as they are known to alter the biophysical and biochemical characteristics of crops. However, manually inspecting an entire crop will take months. Thus, the implementation of an automated disease detection system is necessary. By analysing crop imaging data to monitor improvements in plant biomass and health, pathogens can be identified early on, allowing farmers to interfere and minimize losses for a possible higher yield achievement [31]. The information would be beneficial for the implementation of site-specific disease control (SSDC), an application of pesticides on crops using variable rate applications. It has the benefit of using less pesticide when adhering to the recommended application rate for a diagnosed disease, such as fungicides [47].

3.2.4 Field Robotic

A significant number of studies have been conducted in recent years on the applications of mobile robots for farming activities such as planting, inspection, spraying, and harvesting. In PA, automation and robotics have become a few of the main frameworks that focus on minimising the environmental impact whilst maximising agricultural produce [6].

Agricultural operations must be carried out by using a variety of robots and vehicle systems, depending on the type of land and service criteria. For example, a tractor is highly capable of traversing across muddy surfaces. However, the tractor's massive structure restricts its application to a small area. Thus, agricultural operations in the small area must be executed by mobile robots. The implementation of these mobile robots in agriculture can be categorised based on different agricultural operations, including planting, inspection, spraying, and harvesting. Naik et al. [48] proposed an autonomous seeding robot that has been designed using the Agribot platform, an automated system for measuring soil moisture, weather and crop data based on IoT technology. Additionally, this tool is capable of visualizing real-time results, performing analytics, and generating automatic reports. An infrared (IR) sensor was also used to track the state of the seed tank and detect crop rows. Hence, the proposed technique enables an efficient seed sowing.

Park et al. [49] designed a fruit-and-vegetable harvesting robot that can harvest a variety of fruits and vegetables without any additional or complex control. The designed robot's performance was verified through lab and field experiments, which showed a promising success rate of 80.6% and a total harvesting time of 15.5s.

3.2.5 Fleet Management

Agricultural fleet management is the process by which farmers or machine contractors make choices on resource distribution, scheduling, routing, and real-time tracking of vehicles and materials. Fleet management techniques are employed to assist in decision-making to optimise certain aspects for the more efficient performance of the tedious management task [50]. Additionally, fleet management encompasses the method of supervising the usage and operation of machines. Also, the administrative functions associated with them, such as the coordination and dissemination of tasks and related information address heterogeneous scheduling and routing issues.

Achillas et al. [51] developed a voice-driven fleet management system called V-Agrifleet. The system features a voice-driven functionality and facilitates information sharing between all machine-to-machine pairs in the fleet. For example, during a harvesting process, the harvester operator could identify on the map the location and operating status of a selected transport device, such as whether it is traveling to the depot or to a field, whether it is carrying a load or not, or whether a malfunction has occurred. Along with locating transport trucks and farm equipment, the application offers a concise image of the operating status of both main (e.g., harvesters) and secondary (e.g., transport) groups. Each operator offers real-time information exchanged amongst all authorised users through formalised voice commands during distinct events of the service, such as when loading is complete or when harvesting in a field is complete. By using the V-AgriFleet app, the fleet is contextually conscious of each unit's operation and therefore adapts the configuration to their detected statuses by empowering them with decentralised decision-making capabilities.

Table 3: Summary of VRA in PA.

Application of Precision Farming	References	Technologies	Summary
Traceability	[37]	GIS	A decision support framework capable of storing, managing, analysing, and visualising all types of knowledge (agriculture data, plot data and pest and disease data) on a single platform
	[38]	GIS	Uses nuclear magnetic resonance profiling on GIS data of durum wheat fields to evaluate metabolic expression of durum wheat for selective watering and herbicide spraying
	[1]	GPS	GPS implemented on agricultural machinery helps coordinate location and time information for crop sampling purposes.
	[1]	Satellite imaging	GPS mapping functions
	[39]	Aerial photography	
Information-driven crop production	[42]	IoT-based monitoring and advisory system	The integration of microcontrollers and sensor nodes on an IoT-enabled platform for crop monitoring
	[43]	IoT-based monitoring and advisory system	Utilized an IoT-based sensor network to collect environmental data and proposed a fuzzy logic algorithm based on the data to determine suitable cropping window with minimum pest growth for crop production
	[2]	GPS	Collecting georeferenced data to impose on crop production decisions
	[2]	GNSS	
	[41]	Remote sensing	A systematic data collection of crop nutrients and health conditions over large geographical areas
Site-specific farming	[31]	SSWM	Selective herbicides spraying on crops according to management zones
	[45]	SSWM	A weed control system that utilizes camera and color sensors for automatic localization and recognition of vegetable plants
	[46]	SSNM	A system recommendation on the application of a suitable amount of fertilizer to crops at the appropriate growth stage
	[47]	SSDC	Pesticides are applied to crops in small amounts that do not surpass the application rate suggested for the detected disease.
Field robotics	[48]	Agribot	The Agribot platform was used to develop an autonomous seeding robot. An infrared (IR) sensor was used in this production to track the state of the seed tank and to detect rows.
	[49]	Harvesting robot	Designed a universal fruit-and-vegetable harvesting robot
Fleet Management	[51]	Voice-driven fleet management system	A decentralised decision-making platform for agriculture machinery and transportation that integrates voice-activated capabilities and facilitates information sharing between the fleet's machine-to-machine pairs.

4 The Rise of Precision Agriculture in the Farming Industry

The history of PA demonstrates that it has been driven more by technological developments than by advances in information analysis and decision support. For example, when GPS and yield monitors were first implemented in PA, they were seen as technical advancements that could be applied to existing agriculture machinery to increase its value. The incorporation of GPS into agricultural machinery paved the way for many other technical advancements in PA. However, a current shift seems to have occurred in PA towards a greater emphasis on data analysis and decision support systems.

Variable rate technology (VRT) combines both physical and digital technologies, such as on farm machinery, drones with the integration of artificial intelligence (AI), machine learning (ML), deep learning (DL), and hyperspectral imaging [35]. These technologies aid in the development of information analysis and decision support systems in PA. VRT refers to a technology that enables variable rate application of materials in PA [52]. It is one of the most notable advantages for agriculture to come out of the era of digitisation.

4.1 Applications and Technologies

Similar to VRA, VRT in PA can also be further classified into five agriculture applications, including traceability, information-driven crop production, site-specific farming, field robotics, and fleet management. The following subsections present an overview of these applications. Meanwhile, the summary of these application technologies is tabulated in Table 4.

4.1.1 Traceability

The normalised difference vegetation index (NDVI) is a graphical tool used for crop monitoring through satellite or multispectral cameras that uses light reflectance in the visible and near-infrared (NIR) wavelengths to evaluate the amount and health of vegetation in an area [53]. The data collection stages, primarily in crop monitoring and mapping functions, are evolving from conventional multispectral imaging into hyperspectral imaging. Hyperspectral imaging is a more sophisticated technique than multispectral imaging in that it can acquire a precise spectral response to target features [41].

Hyperspectral imaging can detect subtle variations in ground covers and their evolution over time [54]. The more specificity in a scene, the more likely it is that unique crop characteristics and physiological characteristics can be identified. It is now possible to recognise and identify crop pathogens, pests, and nutrient deficits in vegetation, owing to the potential of comparing spectral signatures with variations in plant physiology [55]. Hyperspectral imaging can also identify and classify different types of weeds, wild vegetation, and crop varieties. Each species of vegetation and variety of crops has its unique spectral signature. However, owing to spectral resolution limitations, the retrieved variables' accuracy is frequently limited, and early signals of crop stresses, such as nutrient deficiency and crop disease cannot be detected effectively and Nevertheless, hyperspectral imagery functions are better than multispectral imagery to facilitate a more accurate and timely crop physiological status detection [54].

Hyperspectral data may be analysed by using ML and DL algorithms because they can efficiently process a large number of variables [54]. Researchers have used different ML and DL algorithms with hyperspectral images for agricultural applications [54]. ML and DL have a versatile and effective computational approach for processing the massive volume of data contained in preprocessed hyperspectral images. Although ML and DL models are powerful, one must still bear in mind that large-quantity and high-quality training datasets limit power outperformance [56].

An example of hyperspectral data applications in precision farming utilising ML is presented by Zhang et al. [57]. The authors presented a quantitative estimation of wheat stripe rust, one of three major wheat rust diseases, by using fractional order differential equations to improve the spectral information and reduce noise while the Gaussian process regression (GPR) ML model is used to construct models for estimating the severity of wheat stripe rust disease. Conversely, Li et al. [58] presented a study for predicting the anthocyanin content in mulberry plants through hyperspectral imaging, least squares-support vector machine, and extreme learning machine models. Falcioni et al. [59] adapted AI algorithms in combination with hyperspectral imaging for the accurate classification of eleven lettuce plant varieties.

4.1.2 Information-Driven Crop Production

Smart crop monitoring through the use of IoT technology is the latest state-of-the-art feature in precision farming, with the aim to optimise resource use and crop development through real-time, accurate, and location-dependent adjustments [60]. The more IoT sensors used to track the data points of crop conditions, the higher the possibility of predicting and foreseeing various crop changes and making faster and better decisions. Several technical challenges exist with the massive use of IoT applications in farm management, such as reliability, scalability, and data transparency issues [61]. These issues happen because diverse and high-dimensional data streams from sensors should be ingested in real-time, delivered, and analysed, usually in a short time, to meet the demands posed by several agricultural applications [2]. Hence, these IoT sensors exploit the 5G technology's low power transmission and reliability given that PA relies heavily on event monitoring that demands data stream processing and consequently requires lower latency and higher bandwidth [62]. Therefore, the superfast 5G network will play a critical role in this PA application [4].

With the advent of smart crop monitoring integration with cloud computing and IoT technologies, a challenge arises in dealing with large-scale analysis of agricultural data [13]. Big data are expected to play an essential role in the PA domains. High-performance, scalable learning systems for data-driven discovery can turn farm management systems into AI systems, providing richer real-time recommendations and automation of several agricultural procedures [2]. Raw and unstructured data captured via several pre-configured IoT sensors are sent to the cloud for processing with the help of big data analytics. The processed result simultaneously and automatically reaches the customers. In agriculture, the decision-making trends have been passed down through generations of farmers; but now, with the advent of advanced computational technologies and complex data processing capabilities, the massive data being captured daily can be exploited to establish a Decision Support System (DSS) for smart farming [13]. The collaboration of Big Data with Cloud Computing and IoT technologies has transpired a new range of applications spanning the area of agriculture [13]. Although big data are widely used in agriculture, they are only relevant in some instances, depending on the farm and its degree of technology acceptance [63]. Kamilaris et al. [64] cited 34 works where big data were used in agricultural applications. Factors such as climate changes, crops condition, and farmer's decision-making, play an important role in adopting big data practices.

4.1.3 Site-Specific Farming

Precision irrigation techniques presented in [31] is a water management site-specific technique that aims to improve the efficiency of water use so that the resource is applied effectively in the right places at the right time and in the right quantity. Detecting the areas where major irrigation is needed can help the farmers save time and water resources.

In addition, a water management model mentioned in [1] is capable of monitoring and scheduling daily crop water requirements within an observed grid. This GIS user-interface technique linked with the water management model as shown in Figure 3 is capable of assisting and improving the decision-making process in water management based on parameters such as the irrigation requirement, rainfall, effective rainfall, and drainage requirement.

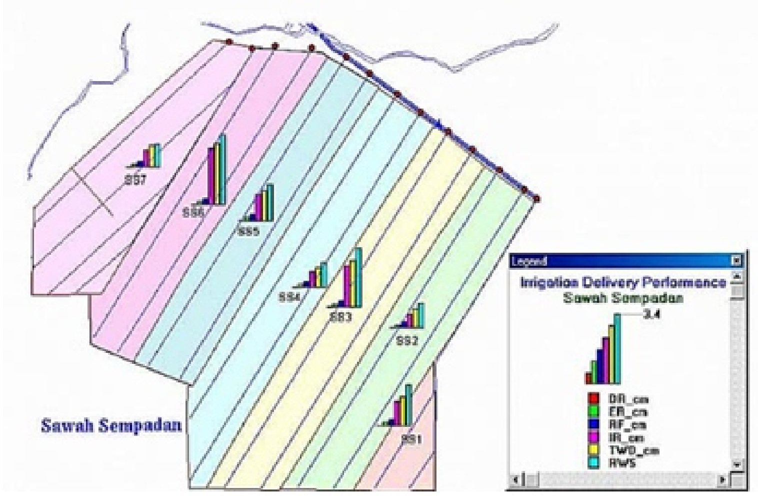

Figure 3: GIS-based computer model to compute spatial water requirement [1].

Targeted spraying of herbicides, fertiliser and pesticides is also a major contribution in site specific farming to ensure the right amount of chemical is applied at the right time to obtain optimal yield and minimise its negative impact on the environment. Stajnko et al. [65] proposed a targeted spraying method on an apple orchard that selectively delivers pesticide spray with respect to the characteristics of the targets. The density of an apple tree canopy was detected by ultrasound sensors controlled by a microcontroller. The analysis focused on the detection of appropriate thresholds on 15 cm ultrasound bands, which corresponded to maximal response to tree density, and this feature was selected for accurate spraying guidance. The employment of this method showed a reduction in the amount of spray delivered by up to 48.15%.

Apart from using pesticides, biological solutions are being implemented to control the excessive usage of chemicals in agriculture practice [66]. Metarhizium Anisopliae is an Entomopathogenic Fungi (EPF) that acts as an environmentally friendly biological control agent for rhinoceros beetles [67].

An example of crop health monitoring by using intelligent site-specific farming technology was presented by Devi et al. [68]. In particular, the authors proposed an intelligent bean cultivation approach that utilises computer vision, IoT, and spatio-temporal DL strategies for real-time discrimination between healthy and diseased bean leaves, weed detection, and process control, as well as site-specific water sprinkling.

4.1.4 Field Robotics

Advanced technology allows the deployment of autonomous robotics. UAVs, commonly referred to as ‘drones’, are the latest advanced equipment in the field of robotics. Drones are typically associated with military, industrial, and other advanced operations; however, with recent advances in sensor and information technology over the last two decades, the application of drones has expanded to include agricultural applications [30]. Drones are manufactured to become smarter, thereby widening their scope of application in the agricultural sector. Drones provide comprehensive benefits that help to accurately monitor food crops, especially large agricultural crops [3]. Drones can carry out regular air monitoring of crops to identify their status at regular intervals. Site-specific disease control can be implemented by integrating UAVs. UAV-based data processing technologies use crop imaging information to identify changes in plant biomass and their health. Moreover, utilisation of pesticides, water, and fertilisers can be accurately monitored. Such a process is possible because UAV targeting helps in the timely and highly spatially spreading of fertilizer [31].

4.1.5 Fleet Management

Fleet management views prescriptive maintenance and real-time environmental adjustments, aimed at improving performance and extending the useful life of farm equipment and other assets, as well as decreasing the risk of mold, fire, and other threats. Currently, fleet management tools focus on real-time insights not only to improve logistics but also to reduce costs, and create stronger digital connections amongst all the stakeholders. Current fleet management also aims to protect valuable assets, including staff, equipment, inventory and land by identifying the conditions that present a hazard to health, safety or productivity at an early stage [60].

A global telematics platform provider called 3Dtracking proposed an agriculture fleet management system based on a case for industry-specific software solutions [69]. The use of a telematics platform enables farmers to view their farms in accordance with various points of interest (POI). Real-time agricultural transport and machinery, including field robotics detection and operational information, are made available with this tool. Additional features of reports and alerts for the management of these agricultural transport and machinery are implemented allowing for efficient fleet control decision making. Additional functionality for fuel tracking was embedded, and the data is being used to measure and provide insights such as distance covered or working hours in relation to fuel usage. Fuel dispensing at the farm fuel depot is also added to further monitoring of fuel usage in relation to work achieved in the fields. This added procedure helped improve the management of fuel and avoid theft or waste in the case of vehicles idling unnecessarily. With further studies and developments in the future, features such as driver's authentication, behaviour, working hours, and fuel consumption would improve agriculture productivity as a whole.

Table 4: Summary of VRT in PA.

Application of Precision Farming	References	Technologies	Summary
Traceability	[41]	Hyperspectral imaging	Identification of unique physiological crop traits to identify crop diseases, pests, and nutrient deficiencies
	[54]	ML and DL algorithms	Tools for analysing a large number of variables from information captured by hyperspectral imaging.
Information-driven crop production	[61]	IoT technologies	Utilisation of many IoT sensors to track the data points for higher possibilities of predicting and foreseeing various farms' changes to make faster and better decisions.
	[4]	5G communication technology	To ensure real-time data execution with low latency for crop monitoring IoT sensors.
	[63]	Big data	Raw and unstructured data captured via several pre-configured IoT sensors are sent to the cloud for processing with the help of big data analytics.
Site-specific farming	[31]	Precision irrigation techniques	A water management site-specific technique to improve the efficiency of water use by monitoring and scheduling daily crop water requirements.
	[65]	Targeted spraying of herbicides, fertilizer, and pesticides	A programmable ultrasonic sensing system for targeted spraying in orchards that showed a reduction in the amount of spray delivered
	[68]	DL	A tool for crop-monitoring (real-time discrimination between healthy and diseased leaves, weed detection, and process control)
Field robotics	[30]	UAV	Crop monitoring, disease control and crop spraying at regular time intervals
Fleet Management	[69]	Fleet management system utilizing telematics platform	Provides real-time agricultural transport and machinery detection and operational information with 3D POI.

4.2 PA Issue and Recommendations

Agriculture production is heavily reliant on water and soil factors, both of which must be used more efficiently. These resources are managed effectively with the help of PA practices through a set of information technologies (IT) such as GPS, remote sensors, UAV, ML, DL, and many other options [70]. PA is equipping farmers with effective instruments for achieving productivity in agriculture. Different types of sensors, positioning and navigation systems, and variable rate technology are well-known components of PA. Drones and robots are promising tools that enable farmers and managers to collect information or perform particular actions, including irrigation and fertiliser spraying in remote areas or tough conditions [24]. PA adoption can be substantially improved if a combination of more precise and robust sensors specialised for each activity and the end-users (farmers) is applied. This process is done to receive quantified information about the farm profit augmentation and the positive sustainability impact, combined with reduced investment cost [47].

The implementation of PA is not limited to one or two technologies or innovations, as certain technologies and innovations may be applicable in one field but not in others. A useful, practical, and suitable transition to technology is necessary. Each field should have its own set of technologies, such as crop planting methods and customized fertiliser application technology. objective was to achieve site-specific management (SSM) through cost-saving agriculture methods to increase yield production [1]. Table 5 summarises the issues and future recommendations that can help improve PA practices.

Multiple possible future research lines exist in the context of PA, focusing on technologies that have not been researched as often, such as the utilisation of hyperspectral imaging with UAV for crop mapping, which requires further sampling. Although UAVs are currently used in the agricultural sector, their integration with hyperspectral imaging has not been extensively used in PA due to their limited accessibility outside of the scientific community. The acquisition, processing, and evaluation of hyperspectral imaging continue to be difficult tasks due to its large data volume, high data dimensionality, and complex information analysis. Performing a comprehensive and in-depth study of hyperspectral imaging technologies for agricultural applications is therefore advantageous [54].

Table 5: PA Issues and Future Recommendations.

Methods	Issues	Recommendation
Utilisation of hyperspectral imaging with UAVs for crop mapping	Challenging data acquisition, processing, and evaluation of hyperspectral imaging hinders its integration of imaging technologies with UAVs	Perform a comprehensive study on hyperspectral imaging, which requires further sampling
Adopting 5G communication for easy-access to data storage and real-time application	Advances in communication technologies with the implementation of 5G networks in all countries	Mobile operators across the globe should largely contribute to smart agriculture by building out their digital networks to support 5G networks
DSS for crop management	A farmer's lack of PA skills is a major element preventing IT adoption in the agriculture sector. Farmers usually opt to implement hasty trial-and-error tactics, which significantly raise the adoption cost	Introducing a tool or framework that encompasses the required PA knowledge that directly supports the decision-making process of selecting the appropriate technology for a farmer's needs
The integration of hardware and software	The generation of a massive amount of crop data to be processed creates research opportunities. It could help identify new advancements in the context of PA using a variety of methods, providing farmers with useful insights on how to increase yields	Specific attention should be given to research on the optimised methods of PA application to primarily reduce undesired yield and improve the carbon footprint of crops

All countries are expected to introduce 5G networks in all fields; hence, Internet prices are expected to decrease significantly and connectivity will improve [71]. Investment costs for PA are predicted to substantially decrease due to 5G use, which would benefit farmers. Farmers would be well equipped for smart farming, as they would be able to predict and prevent crop diseases via their cell phones. If the implementation of 5G is largely adopted, mobile operators are then required to contribute significantly to smart agriculture by expanding their physical networks to support PA applications. For instance, large sensors will be able to gather data in the field and store it in the cloud, where it can be analyzed whenever convenient [4].

Another essential aspect that future research should focus on is the need for farmers to acquire additional PA knowledge. It has become one of the significant factors discouraging them from implementing IT in their fields. Accordingly, a tool or framework that encompasses this required knowledge and that directly supports the decision-making process of selecting the appropriate IT for a farmer's needs without relying solely on trial-and-error strategies that further increase adoption costs would be highly desirable [70]. The information that the crops offer can only be turned into profitable decisions when they are efficiently managed. PA is growing rapidly owing to recent developments in data management, as data has become a vital component in modern agriculture, assisting farmers with critical decision-making. [63]. Hence, farmers should have a DSS for their crop management decision [1].

The integration of software and hardware solutions has resulted in the generation of a massive amount of data that can be processed by using a variety of methods, providing farmers with useful insights on how to increase crop yields [47]. Considering that the adoption of innovation solutions promises exponential growth in PA application, further research should be carried out to improve the carbon footprint of crops. All these research opportunities could help to identify new advancements in the context of PA [70]. Hence, specific attention should be given to research on the optimised methods of PA application to primarily reduce undesired yield.

PA is forecast to hit USD11,107 million by 2025, rising at a 13.97% compound annual growth rate from 2019 to 2025 [72]. Although advancements in precision agriculture encourage the adoption of innovative solutions, the practice's implementation is constrained by several challenges. The main factors affecting the adoption of PA are as follows [24]:

a) Political and legal support
b) Decision support systems and user interfaces
c) Experienced research team works
d) National educational policy
e) Success in commercialisation of the PA system

The adoption of advanced technologies in PA continues to be critical for progressing towards new and sustainable agriculture capable of illustrating the maximum potential of data-driven management in addressing the complexities of food production in the 21st century. Agriculture 5.0 is a priority over the next decade for the majority of large agricultural machinery manufacturers. Hence, governments, researchers, and industry enablers play a critical role in aiding farmers in agricultural management systems through digital solutions powered by robotics and artificial intelligence [63].

5 Conclusion

To meet the expanding population, agricultural products for food production are predicted to increase by 70% by 2050. However, conventional practices show many signs of inefficiency that negatively impact the environment and yield production. PA is one of the fastest-growing agricultural technologies. PA strives to improve agricultural productivity, land-use efficiency, production costs, environmental quality, and food supply sustainability. Despite expanding research on new technology adoption, PA continues to suffer from a lack of agreement on its conceptualisation. Thus, this research aimed to synthesise the literature on the adoption of agricultural technologies in the farming sector from its conventional era to its current practices. This work has shown that with PA practices, using full mechanisation of high-tech equipment can reduce agricultural inputs through site-specific applications as it better targets inputs to the spatial and temporal needs of agriculture crops. This research provides readers with an overview of the evolution of PA throughout the years, categorised based on five major PA applications. Farm managers and agricultural analysts may find the information in this work beneficial in identifying PA implementations as well as in deciding the PA technologies to be adopted.

6 Acknowledgement

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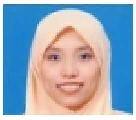

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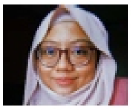

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Space Syntax Analysis on Indoor Anaheim Regional Transportation Intermodal Center

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ABSTRACT

Space syntax is a human-focused approach that supports humans in identifying the relationship between human activities and the spaces within a habited area. This paper mainly focuses on the space syntax defined from the existing case study the Anaheim Regional Transportation Intermodal Center (ARCTIC), USA. Method of utilizing information found from resources like the internet and interviewing the respective parties involved in the building renovation. The Likert scale method is used to present the research finalist, which justifies the wayfinding and permeability of the ARTIC. This paper's finding shows that wayfinding in the ARTIC is instead of a dilemma. Based on the outcome, the ARTIC round spatial arrangement is somewhat supportive for the visitors to seek wayfinding. However, some areas are narrow and dense, which are not suitable to cater to the large volume of visitors. Hence, the finding of this paper hopes to aid in building the designer in future terminal design.
Disciplinary: Architectural Engineering.

Keywords: Human activity space; Space syntax graph; Wayfinding and permeability; ARCTIC; Spatial configuration; Terminal design; circulation; Terminal staff circulation; Transporation hub.

1 Introduction

In 1984, after publishing “The Social Logic of Space” by Bill Hillier (1984), architectural theory related to spatial nature had been improving fast. 'Space syntax' is a social theory of space and a method of analysing the spaces in buildings and urban environment using the analytical and descriptive tool to represent the spatial formation (Hillier and Hanson, 1984, Hillier, 1996). The research objective is to analyse the flow of spaces or permeability (Ephes, 2006) of the selected case study building. This paper uses space syntax and applies it to achieve the research objective and finally determines how the spaces are configured will relate to the way humans perceive and move through the spatial system (Penn et al. 1998). The analysis also includes using a graph to understand and predict user movements (Ratti, 2003).
The case study, Anaheim Regional Transportation Intermodal Center (ARCTIC), designed by HOK Architect, The design team used building information modelling (BIM) to develop ARTIC's complex form, geometry and functions, to navigate the complexities of the building systems, and to study the building's tolerances and environmental performance. This gives way to multiple types of user, and each will have a different level of permeability access and wayfinding according to the spatial building formations (Rahaman, 2019). This iconic facility symbolised a new public transit era and was only made possible because of city leaders' unwavering commitment to a contemporary and bold design. The

Anaheim Regional Transportation Intermodal Center (ARTIC) in Anaheim, Calif., has earned national recognition in the 2015 Innovative Design in Engineering and Architecture with Structural Steel awards program (IDEAS2). In honour of this achievement, the project team members were presented with awards from the American Institute of Steel Construction (AISC) during a ceremony at the facility. The analysis also includes graphs to understand and predict user movements (Ratti, 2003).

2 Literature Review

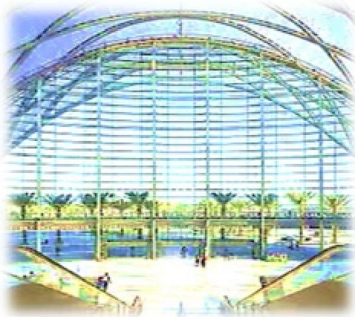
The syntax of space is a method for defining the relationships between human activities and space Within an inhabited area (Bafna, 2003). Investigation of human movement's spatial change The primary goal of space syntax is from one field to another. Spaces and connectivity for transform during the analysis method, space syntax analysis also occurs, often represented by the Permeability degree that lies in constructing buildings. However, the building architecture is focused on The intention and functions that were to be represented by the designer. It is possible to consider space syntax as an accessibility analysis of graphs to derive wayfinding results (Yusoff, 2019). And Kevin A. The phrase for his book "The Picture of the City" was, used by Lynch (1960), where he described wayfinding as wayfinding. “Consistent use of definite sensory inputs from thenatural world to be coordinated.” In another “The syntax of term, space enables individuals to examine the connection between human activities and Spaces in all distinct ways from populated area's structure” (Penn, 2003). The normal to coordinate themselves, communities also use space as the keyword and the necessary details.
Van Nes & Yamu (2021) discussed basic concepts, complex theories, and applications underlying space syntax. Rashid (2019) explained the fundamental concepts, methods, and measures of space syntax configurational approach, highlighting on the axial and segment map analyses, and combining space syntax with GIS.

Mohamed (2012) explored wayfinding ability in city. The results showed that, of an environment, spatial configuration and spatial cognition are highly related giving that space syntax technique provides good predictions of wayfinding ability. Also the study showed that visual form and spatial configuration are highly connected.

3 Anaheim Transportation Intermodal Centre

Anaheim Transportation (Figure 1) is known as the new pulse of the United States, where the transportation capable of that would become an icon for public transit. It needed to encourage Orange County's three million residents with annual visitors more than 50 million, think toward future of sustainable smart travels. The Anaheim Regional Transportation Intermodal Center (ARTIC) serves southern California with a flexible, futuristic terminal for rail, bus and auto passengers in addition to bicyclists and pedestrians. The parabolic design concept of diamond shaped steel arches infilled with translucent ETFE (ethylene tetrafluoroethylene) creates a grand, light-filled atrium space reminiscent of the world's great passenger terminals.

(a) Anaheim transportation (ARTIC) from the opposite road view.



(b) The interior entrance of the Anaheim transportation

(c) The main sheltered entrance of Anaheim transportation from the construction

Figure 1: Anaheim Regional Transportation Intermodal Center (ARTIC), Anaheim, CA, USA (continued). (public domain images with re-digital master enhancement).

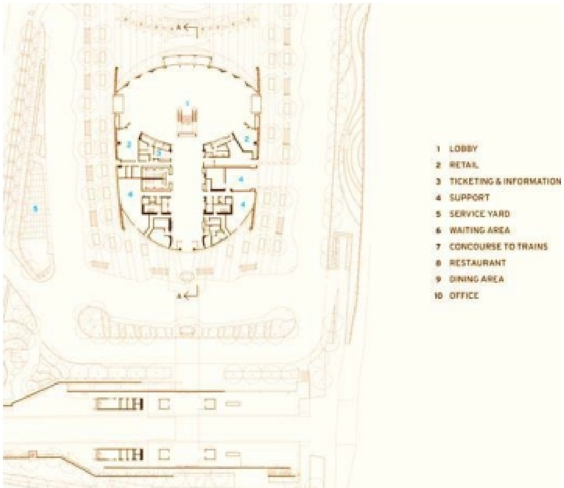
Strategically located in Anaheim's "Platinum Triangle," an area that includes Angel Stadium and the Honda Center, ARTIC is near multiple points of interest including the Anaheim Convention Center and Disneyland. A connection to an adjacent pedestrian and cycling trail along the Santa Ana River opens ARTIC to non-vehicular traffic. Its master plan establishes a clear pedestrian pathway to future mixed-use development. The building's landscape architecture complements both its operations and surroundings. Date palms and olive trees within ARTIC's outdoor plaza create shaded seating areas for riders while succulent gardens add vibrant colours and texture. These drought-tolerant plantings are irrigated entirely from rainwater and greywater, contributing to the building's 80 per cent reduction in potable water consumption.

The Phantom, transportation has been deliberately built to fill several usable spaces inside and enable immense spectator capacities to be held in a period per event. People with the same intent are social, educational, recreational, service, and other purposes, using a public or private.External preparation, wayfinding & permeability levels must cater to the high degree of permeability—the sum of human movement to prevent all forms of needless trouble. Specific sentences and control of the Securities and entry egress are also the most crucial obstacles in transportation architecture. This research examines the positive and negative implications of the picked case study and provides data to strengthen future design of transportation center and facilities.

The Anaheim Regional Transit Intermodal Hub (ARTIC) is an optimistic showcase of the future mass transport in southern California.

(a) Critical Plan Anaheim

(b) location plan Anaheim



(c) The site plan Anaheim

Figure 2: Plan Anaheim

4 Method

The selection of a proper case study for space syntax is crucial to start for this research. The case study selection must have comparative typology with the design thesis topic. However, the circular space syntax graph is being introduced in this case due to the circular space syntax graph able to fulfil the placement and circulation of the Anaheim Transportation Intermodal Centre. The circular space syntax graph with permeability will be differentiated by the colour zone growing from the outermost line toward the Centre point. Meantime, building levelling will be indicated based on the mainline's position. Spaces relationship can be presented in the more natural form due to all the labelling and symbols able to place accordingly. As the research proceeds further, different kinds of presentation graph methods will need to be introduced. Due to the circulation design of the Anaheim Transportation Intermodal Centre are in the form of a loop. All the spaces within able to be connected through a continuous walking corridor. Besides that, multiple entrances are situated around the terminal, allowing the ingress and egress to be happening around. Conventional vertical and horizontal space syntax graphs challenge the flow of connectivity and the level of permeability.

5 Results

This analysis will start from the ground floor plan. This result will be carried out specific to each user category. Their circulation to go through all space will be translated into a graph format from which the depth permeability may be understood. The three user categories are Tourists and Staff Terminal. Figures 3, 4 and 5 are the floor plan for the transit terminal with a code that corresponds to the provided list of spaces with code and space name, accommodation schedule for the ground floor, first-floor plan, and mezzanine floor plan. The images were also redrawn to illustrate based on the images provided by the pinterest.com.

Figure 3: Ground Floor Plan Indication,

There are three main entrances (grey colour indication) on the ground floor that mainly serve the vehicular ingress and egress. The current ground floor plan contains six colour indication for part of the transit terminal. For the yellow colour indication that for the circulation in transit terminal, red colour indicates that for the commercial tenant space, the orange colorindication of the landscaping area, the grey color indication of the lobby and waiting area, the blue color indication for ticket counter, and last is the green color transportation operation.

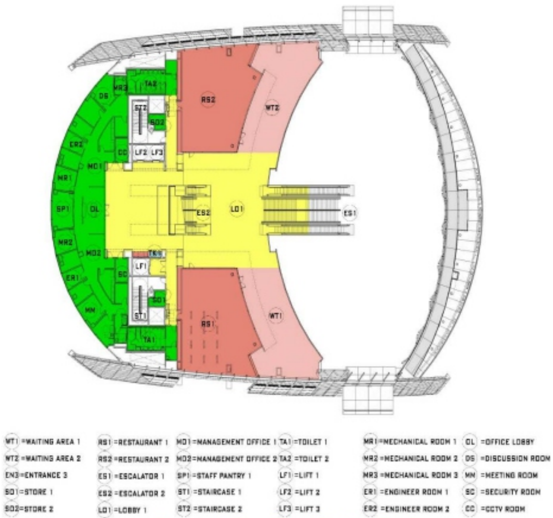


Figure 4: First Floor Plan Indication,

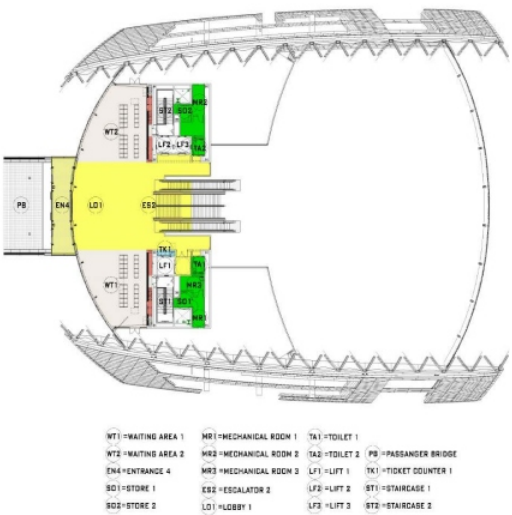


Figure 5: Mezzanine Floor Plan Indication,

5.1 Tourist Circulation

Figure 6, tourists have a generally straightforward flow that begins from the car drop off or bus terminal. Their access to the transit terminal has three entrance (EN1-EN3). The terminal lobby (Lo1), fluidly linked to the ticket counter (TK1-TK2), cafe (CA1-CA2), restaurant (RS1-RS2) and access way to the first-floor level that lifts (LF1-LF2), escalator (ES1) and staircase (ST1-ST2).

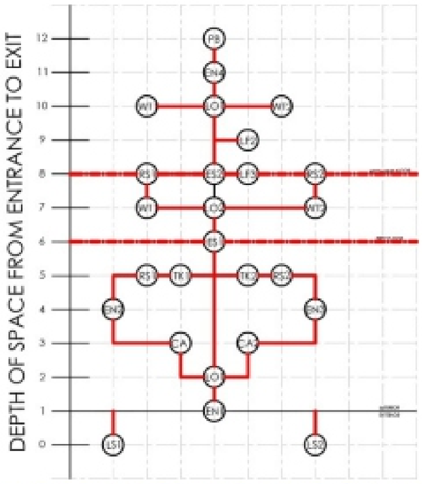


Figure 6: Measurable scale graph for tourist circulation

At the first floor level the tourist needs to through by lobby 2 (LO2) and their can to waiting area at (WT1-WT2) and restaurant (RS1-RS2) also can get the ticket at the counter ticket (Tk1). After getting the confirmation for a travel document, the tourist will go through the escalator 2 (ES2) to go mezzanine floor to departure. That have lobby (LO1) or waiting for the area (Wt1-Wt2). Some tourists can use the lift (LF1-LF2) facilities to shorten the walking step distance.

5.2 Terminal Staff Circulation

Through Figure 7, the terminal staff work at the first-floor level. Only the specific staff like a receptionist who works at the ticket counter (TK) located at the terminal lobby 1 (Tl1). They will enter via the entrance through by escalator 1(ES1) it is connected to terminal lobby (TL1) or management office (MO1-MO2) where the staff that duty at ground floor level.

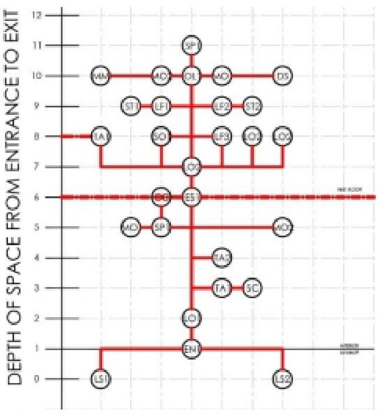


Figure 7. Measurable scale graph for terminal staff circulation

The staff can use the lift (LF1) or staircase (ST1-ST2) to going to the office space upstairs.The terminal staff like administration have their own office space at this first-floor level. At the first-floor terminal lobby (Lo2), there are three branches directly to the office space (MO). The office lobby (OL) located at

the end of the building was also located the high management office (MO1-MO2), discussion room (DS) and meeting room (MM).
The architect-designed the management office must have a high depth permeability space where the high-ranking officers work there and the staff that deals with tourists or passengers must have a low-depth permeability and be close to the terminal lobby. The primary circulation, especially for the international gate where the foreign enter and out of the country, must through the standard operating procedure.

Discussion

There are categories of visitors and users (Purpose of Visit) who visiting Anaheim Transportation. Method for categorising them will relate to the function of Anaheim itself closely. First, Anaheim Transportation is mainly designed to cater to "Transportation". Transportation can be closely linked to the bus, LRT, taxi, and monorail, which involve public space. Visitors who come for such a transit often have a specific direction while walking in Anaheim. They will direct themselves toward the transit area based on the entrance indication after entering the building. However, wayfinding is very different for the transit such as organising a transit for a particular transit.
Such transit often encourages the visitor to move around Anaheim's internal layout. The level of permeability is often hardly able to apply due to different motives having. Commonly terminal will maximise the functional spaces as much as possible. It is tough to control the visitor movement while there are multiple entrances around Anaheim. High visitor volume usually will affect human change also. Most visitors often like to find the shortest travel distance to travels within the building. However, the third phenomenon often happens to the visitor who travels to Anaheim Transportation to visit the offices or the office workers. We can find office within Anaheim such as Terminal Lrt and office are located around the first floor. The visitor often moves from one to another due to all circulation on the ground floor. Ground floor plan circulation often makes the visitors confuse for the direction.

6.1 Wayfinding in the Ground Floor

Ground floor layout presented in a high ceiling and big space designs. The visitor must go through many tiers of the compartment to reach their destination. The overall experience of the ground floor given for the visitor is very appropriate due to the reasons mentioned. The circulation will lead to the back of the house quickly.

6.2 Wayfinding in the First Floor

The visitor who settles their activity on the ground floor can get ES1 to go straight to the first floor. The first floor has a direct and straightforward wayfinding for office and waiting area. However, a visitor who came for the counter ticket and entrance can relax and chill on the first floor. The overall user experience for the first floor is slightly better, and it has felt welcoming in the way of the design approach.

6.3 Wayfinding in the Mezzanine Floor

The mezzanine floor has straightforward wayfinding for waiting area because from the first floor, and the visitor goes straight to entrance(EN4) to get the LRT, monorail, and bus. However, a visitor who came from the first floor has nothing to do the mezzanine floor just only for departure. Having studied space syntax analysis on the indoor arena of the Anaheim Transportation, California, the summarised result is given in Table 1.

Table 1: Summarised permeability result of Anaheim Regional Transportation Intermodal Centre, California

Element	Very easy	Easy	Neutral	Hard	Very hard
Ground Floor	✓				
First Floor		✓			
Mezzanine Floor			✓		

7 Conclusion

This paper mainly focuses on the space syntax for the case study the Anaheim Regional Transportation Intermodal Center (ARCTIC), USA. Method of utilizing information to form color zone for each floor. The Likert scale method is used to present the research finalist, which justifies the wayfinding and permeability of the ARTIC. This paper's finding shows that wayfinding in the ARTIC is very easy for the ground floor, easy for the first floor, and neutral for the mezzanine floor. Based on the outcome, the ARTIC round spatial arrangement is somewhat supportive for the visitors to seek wayfinding, even though some areas are narrow and dense not suitable to cater to the large volume of visitors.

8 Availability of Data And Material

All information is incorporated in this article.

9 Acknowledgement

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Space Syntax Analysis on Indoor Sports Center Jules Ladoumegue France

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ABSTRACT

This paper studies and reviews the level of permeability and wayfinding of indoor sports centers by using space syntax analysis. The case study selected is Indoor Sports Center Jules Ladoumegue, France, which has an office and public access. This study applies the labeling system using alphabets and numbering systems and then turns into space syntax analysis of measurable scale graphs on the level of permeability and wayfinding. This analysis classifies the measurement into nine levels of the Likert scale's permeability. The finding shows that it has two separate access spaces: the office and the indoor sports center. The office consists of two floors while the sports center consists of four floors. This study shows that this indoor sports center has moderate wayfinding and permeability levels. Each space is easy to access, and some spaces are linked with another space.This building is neutral in its space syntax analysis. The top level of permeability is at the rooftop, the patio, squash area, dance, and gym space.
Discipline: Architecture Engineering.

Keywords: Space hierarchy; Sport building; Wayfinding; Spatial arrangement; Permeability; Sports center; Access space; Moderate wayfindinglevel; Moderate permeability level; Sport facilities; Sport complex; Public space.

1 Introduction

This research paper aims to better understand of space syntax by analyzing and providing an in-depth study of the selected case study area. Space needs to consider the capacity to regulate and not only depend on the degree of privacy (Yusoff and Hassan, 2019). This building is a public building and an indoor building that provides a place to play sports and live a healthy lifestyle.

People are known to spend most of their time indoors (Mehdipour & Nazamian, 2013). This building is analyzed based on its wayfinding, permeability, spatial arrangement, and space hierarchy. This theory of space syntax analysis is widely used in space planning such as wayfinding. (Beck and Turkieniez, 2009). At the end of this research, the findings will show how this sports complex can navigate inexperienced users throughout the complex. The findings will include the design weakness and strength of the spatial arrangement. In this case study, space syntax will help identify the connection between human activities and the habited spaces (Bafna, 2003). This research will help in the future designing process of the spatial arrangement in a sports complex and as a reference to others.

2 Literature Review

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Space syntax proposes a reverse approach to studying urban morphology and human behaviors. (Vaughan, 2007). Space syntax is defined as a method to study the relationship between space, spatial structures, and human behaviors. (Liu et al. 2018). The common practice by architects is spatial configuration, and it represents the consequential process regarding the function (Mustafa and Hassan, 2010). The objective of space syntax is to investigate human movement transition from one space to another. A proper space syntax will ensure the building functions efficiently over time (Mustafa and Hassan, 2010). In architectural design, space syntax is one way to collect information and analyze it, which is later translated into drawing format (Asif et al., 2018). It is the process of transforming abstract design ideas into physical spatial installations. Lawson (1997) discussed the meanings inherent in the word "design" vary according to different career groups, and its only common point is that it is an unusual and complex activity. A justified graph is an analysis from space syntax according to syntactic step, and depth (Hillier et al., 2016).From this justified graph, the depth levels will influence the shape at the end (Natapov et al., 2015). This sports center focuses on sports activities where the public will enjoy a healthy lifestyle. In planning successful spatial development, it is a must for public space, and private space configurations must be designed accordingly. (Hassan, 2019)
According to Hiller and Hanson (1997), the design is a process that moves from an unknown state into one that is known. Architecture is a practice of "thinking by doing" led by data from various sources and different types of information in which intuition and science are brought together (Dursun, 2007). When it comes to the architectural design tool, it is about a set of methods, mechanisms, tools, and apparatus that help translate the idea from one mind to another. The designer uses these tools in the thinking process and so such tools are not limited to the kinds of physical objects we use while designing the ideas that are first conceived in our minds (Şişman, 2015). The permeability is known as the satisfaction of peoples' opinions based on the environment's properties (Hölscher, 2012).

3 Case Study: Indoor Sports Center Jules Ladoumegue, France

The case study chosen is a sports center located at 37 Route des Petits Ponts, 75019 Paris, France. This sports center has sports facilities consisting of a soccer field, rugby field, indoor wall climbing, tennis court, basketball court, gym, dance studio, fitness room with grandstands, changing facilities, and offices. The sports center was completed in 2014 and designed by Dietmar Feichtinger Architects. This sports center is integrated with the stadium next to it, making it complete as a public sports center. According to Hiller and Hanson, the design integrates intuition and reasoning (Hiller and Hanson, 1997). The Tennis Courts are part of the Jules Ladoumegue Sports Complex, which was awarded a Bronze medal in 2015 by the International Olympic Committee.

3.1 Design Detail of the Sport Center Jules Ladoumegue

This building was selected because it was designed vertically upwards, making every floor have different sports facilities. The rooftop is where the sports fields for soccer and rugby are located. This sports complex consists of a few blocks with different sports usage such as a block facing the East with four floors dedicated to sports activities. This sports center is designed for public usage as it is located next to public transport, the tramway line T3, and the RATP (transport service Ile-De-France), which makes it easy to access.

Figure 1: Sport Center Jules Ladoumegue
(Courtesy of Dietmar Feichtinger Architects).

4 Methodology

In this part of the methodology, the case study selection is crucial as it needs to align with the design thesis topic. A proper case study will have useful information on space syntax, the level of permeability, and wayfinding. Wayfinding is the consistent use and organization of definite sensory cues from the external environment. (Lynch, 1960). There are two types of methods used to study the space syntax and level of permeability. This paper used a common integration value (Hillier and Hanson, 1984). First, the labeling system's method uses alphabets and numbers. This system applies in determining the level of permeability from public to semi-public to semi-private and private. In this method, the labeling will start from 0(Public) up to 7 (Private).

Every number represents the space arrangement within every floor plan. For example, the ommon area or the lobby will be represented with the Number 0, and then the next space will be labeled as number 1 and up to offices with the number 7(most private). For spaces such as the main entrance, and lobby, linkage to other spaces will be represented by the alphabet P. (P1, P2, P3, etc.) The sports facilities such as the gym, dance studio, and fitness room will be represented by the alphabet S, (S1, S2, S3, S4, etc.) For toilets, it used alphabet (T1, T2, T3 etc.) staircase (SC 1, SC2, SC3 etc.) elevators (L1, L2, L3 etc.) and offices (O1, O2, O3 etc.).

The second method to be used is the Justified Graph method. The numbering and alphabet labeling are then translated into the Justified Graph to obtain permeability and wayfinding in space syntax study. In this Justified Graph, a graph is drawn to obtain the result for conclusion later.

3.1 Method of Analysis

The spatial building structure is analyzed based on the type of users. From the types of users, the depth levels of permeability will be obtained and can determine access from public to semi public to semi-private and private. It was found out that the users of this Sports Center weredivided into four types. There are public users, specific users, office staff, and visitors. The levels of depth or steps will directly affect how the justified graph looks at the end, whether deep or shallow (Natapov et al., 2015).

4.2 Synthesis of Data

The result is then categorized according to hierarchical order to identify permeability and wayfinding levels. The wayfinding will be analyzed from very easy to medium to difficult and to very difficult from the findings. For permeability, access is categorized from primary to secondary, tertiary, and other levels.

5 Results of Analysis

The result for permeability and wayfinding will be divided into each case study floor. The floors are the ground floor, first floor, second floor, and third floor. The permeability depth is translated into a measurable scale graph for better understanding.

5.1 Ground Floor Plan

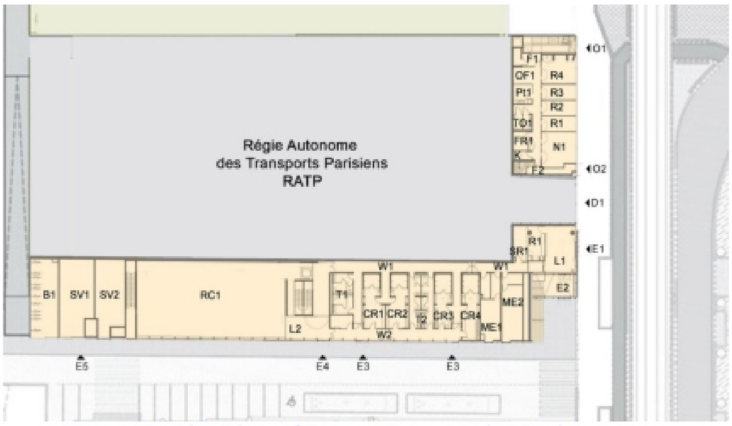

Figure 5: Site Plan of Sports Center Jules Ladoumegue.

The analysis of the case study will start from the Ground Floor Plan. Figure 5 shows the site plan, and Figure 6 shows the measurable scale graph for the ground floor. Table 1 is the schedule of accommodation for the ground floor plan.

Table 1: Schedule of Accommodation Ground Floor Plan

CODE	SPACE	CODE	SPACE
E1	Entrance 1	K	Store
E2	Entrance 2	T1	Toilet 1
E3	Entrance 3	T2	Toilet 2
E4	Entrance 4	CR1	Changing Room 1
E5	Entrance 5	CR2	Changing Room 2
D1	Entrance to RATP (Régie Autonome des Transports Parisiens) Hub	CR3	Changing Room 3
L1	Lobby 1	CR4	Changing Room 4
L2	Lobby 2	ME1	Mechanical Room 1
R1	Reception 1	ME2	Mechanical Room 2
SR1	Staffroom 1	RC1	Rock Climbing Space
W1	Walkway 1	B1	Bicycle Room 1
W2	Walkway 2	SV2	Service Room 2
SV1	Service Room 1	R1	Room 1
OF1	Office 1	R2	Room 2
O1	Office Entrance 1	R3	Room 3
O2	Office Entrance 2	R4	Room 4
F1	Foyer 1	FR1	File Room 1
F2	Foyer 2	N1	Meeting Room Office 1
Pt1	Pantry 1	TO1	Toilet Office 1

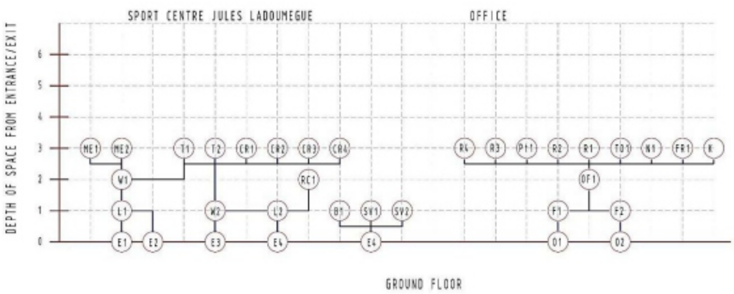

Figure 6: Measurable scale graph for ground floor

The depth levels of the justified graph are three levels. The analysis of the ground floor can be divided into two separate functions. The offices for the staff and the sports facilities are for the public. The office entrance is separate from the sports facilities as it enters O1 and O2 referring to Figure 5. As the staff enter, they will direct foyer 1 and foyer 2. From the foyer 1 and 2, the move to the office area. They will be directed to other rooms from the office area: the meeting room, file room, pantry, and toilet. In this office, the depth levels of permeability are private and separate from the public. The depth levels of wayfinding are straightforward as the staffenter and only 3 levels of depth.

It has multiple entrances for sports facilities from E1, E2, E3 and E4. The visitors come from E1 and E2 will go to Lobby 1. Visitors coming from E3 will go to walkway 2 while entrance from E4 leads to Lobby 2. From Lobby 1, visitors will go to walkway 1 and then to changing rooms and toilets. Visitors in Lobby 2, will go to the Climbing space. Visitors at walkway 2 will enter directly to changing rooms and toilets. The depth level of permeability for sports facilities is from public to semi-public. It is considered easy and straightforward for visitors to easily access spaces for way finding levels.

5.2 First Floor Plan

Figure 7 shows the first-floor plan, and Figure 8 shows the measurable scale graph for the first-floor plan. Table 2 is the schedule of accommodation for the first-floor plan.

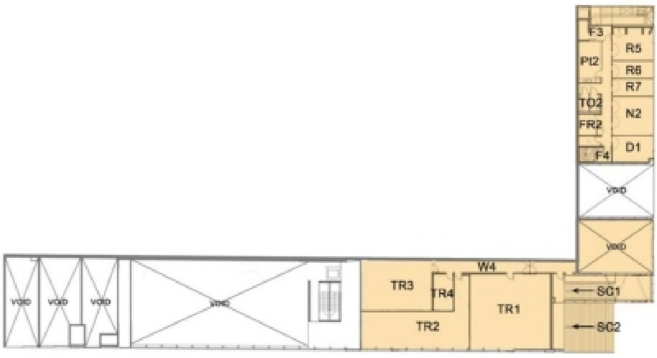

Figure 7: First Floor Indication

Table 2: Schedule of Accommodation 1st Floor Plan

CODE	SPACE	CODE	SPACE
SC1	Staircase 1	TR3	Technical Room 3
SC2	Staircase 2	TR4	Technical Room 4
TR1	Technical Room 1	OF2	Office 2
TR2	Technical Room 2	W4	Walkway 4
F3	Foyer 3	FR2	File Room 2
F4	Foyer 4	R5	Room 5
Pt2	Pantry 2	R6	Room 6
TO2	Toilet Office 2	R7	Room 7
D1	Director Room 1	N2	Meeting Room Office 2

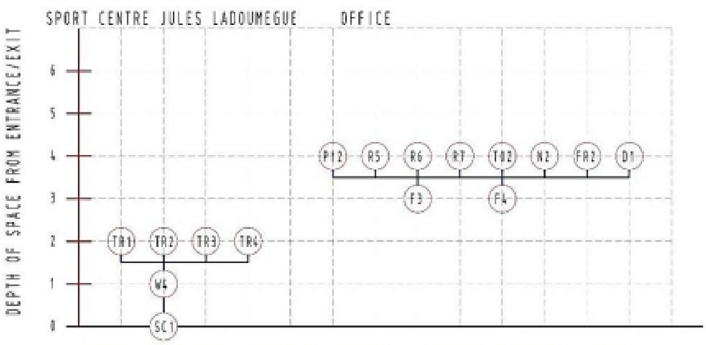

Figure 8: Measurable scale graph for first-floor plan

The depth levels of the justified graph are 4 levels. As the staff move, they will enter foyer 3 and foyer 4. From foyer 3 and 4, staff enter the office and then to other rooms such as pantry 2, room 5-7, meeting room 2, file room 2, and director room. The depth levels of wayfinding are straightforward as the staff enters only 4 levels of depth. For sports facilities on the first floor, only consist of technical rooms 1-4. Technicians enter from Staircase 1 and are directed to Walkway 3 and then to technical rooms 1-4. It is considered very easy for wayfinding as technicians can easily access spaces.

5.3 Second Floor Plan

Figure 9 shows the first-floor plan, and Figure 10 shows the measurable scale graph for the second-floor plan. Table 3 is the schedule of accommodation for the second-floor plan.

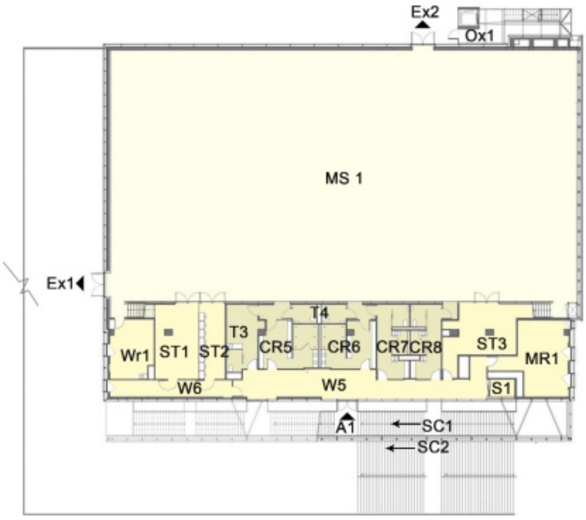

Figure 9: Second Floor Indication

Table 3: Schedule of Accommodation 2nd Floor Plan

CODE	SPACE	CODE	SPACE
SC1	Staircase 1	MR1	Meeting Room 1
SC2	Staircase 2	T3	Toilet 3
A1	Access 1	T4	Toilet 4
W5	Walkway 5	CR5	Changing Room 5
W6	Walkway 6	CR6	Changing Room 6
Wr1	Workshop 1	CR7	Changing Room 7
ST1	Storage 1	MS1	Multisport Hall 1
ST2	Storage 2	Ex1	Emergency Exit 1
ST3	Storage 3	Ex2	Emergency Exit 2
S1	Service 1	Ox1	Office Exit 1

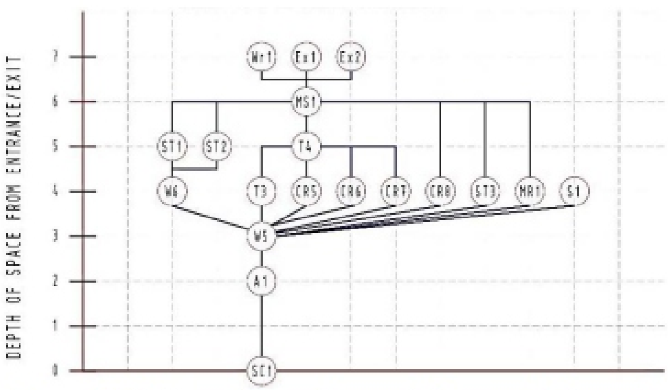

Figure 10: Measurable scale graph for second-floor plan

The justified graph's depth levels are 7 levels for sports facilities on the second floor. To access the second floor of the sports facilities, visitors need to use Staircase 1, which is mainly used by the public. Staircase 1 is the main access from the ground floor to the top floor. From Staircase 1, the visitor will enter Walkway 5, and it is for the public. From Walkway 5, the visitor will move to the next depth of permeability which is semi-public consisting of toilet 3, changing rooms 5-7, walkway 6, storage 3, and meeting room 1. From Walkway 6, visitors can move to Storage 1-2 and separate from Walkway 5. Storage 1-2 is considered as semi-public. Visitors can access Multisport Hall from storage 1-3 and changing rooms 5-7 only, making the Multisport Hall semi-private for visitors only. One private space is the workshop as it is only accessible from the multisport hall. There are two emergency exits Ex1 and Ex2 from the multisport hall. It is considered a medium for wayfinding levels to enter the main Multisport Hall the visitors need to pass through 2 levels of depth that have many spaces. It can be confusing sometimes.

5.4 Third Floor Plan

Figure 11 shows the first-floor plan, and Figure 12 shows the measurable scale graph for the third-floor plan. Table 4 is the schedule of accommodation for the third-floor plan.

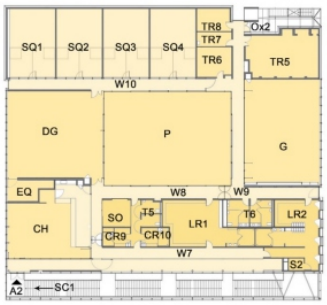

Figure 11: Third Floor Indication

Table 4: Schedule of Accommodation 3rd Floor Plan

CODE	SPACE	CODE	SPACE
SC1	Staircase 1	LR1	Locker Room 1
A2	Access 2	LR2	Locker Room 2
W7	Walkway 7	CR9	Changing Room 9
W8	Walkway 8	CR10	Changing Room 10
W9	Walkway 9	P	Patio
W10	Walkway 10	DG	Dance & Gymnastics
T5	Toilet 5	EQ	Equipment Room
T6	Toilet 6	G	Gym
SO	Small Office	TR5	Technical Room 5
CH	Clubhouse	TR6	Technical Room 6
SQ1	Squash 1	TR7	Technical Room 7
SQ2	Squash 2	TR8	Technical Room 8
SQ3	Squash 3	Ox2	Office Stairs 2
SQ4	Squash 4	S2	Service 2

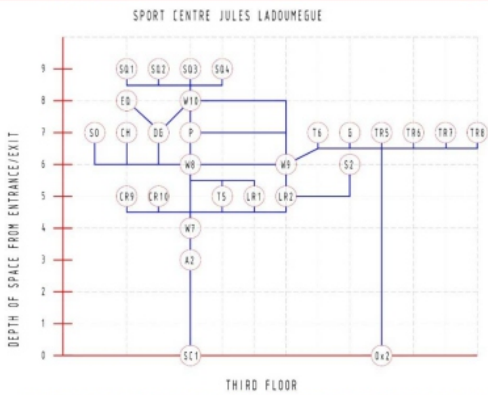

Figure 12: Measurable scale graph for third-floor plan

The justified graph's depth levels are 9 levels for sports facilities on the third floor. To access the third floor of the sports facilities, visitors need to use Staircase 1, which is mainly used by the public. Staircase 1 is the main access from the ground floor to the top floor. From Staircase 1, the visitors will enter the Walkway 7, and it is for the public. From Walkway 7, the visitor will move to the next depth of permeability which is semi-public consisting of changing rooms 9-10, walkway 8, and locker rooms 1-2. From walkway 8, visitors move to the clubhouse, dance & gymnastics, patio and walkway 9. The small office is accessible from walkway 8, but it is private only for staff. The clubhouse, patio, dance, and gymnastics are considered semi-public and only accessible by the sports center's visitors. Toilet 6 is semi-public as the access only from walkway 9. The workout gym is accessible only from walkway 9 and is considered semi-private. Walkway 10 is accessible from the patio and walkway 9. It is a private walkway as it leads to squash 1-4. Squash 1 to 4 is consideredprivate as it is the highest in permeability depth.

It is quite clear that wayfinding is considered a medium for entering each space. Visitors can easily access every walkway, and each walkway leads directly to the spaces. As it went in-depth, the visitors will find it difficult to find the squash 1-4 ais separate by walkway 10. Technical rooms 5-8 are accessible from office stairs 2 directly from the ground floor.

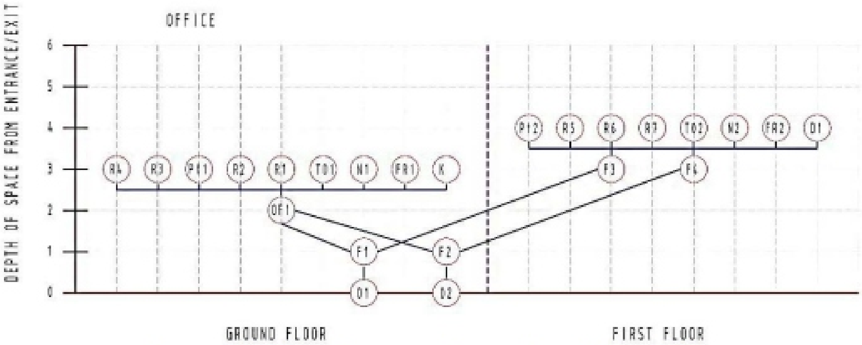

Figure 13: Overall measurable scale graph for Office

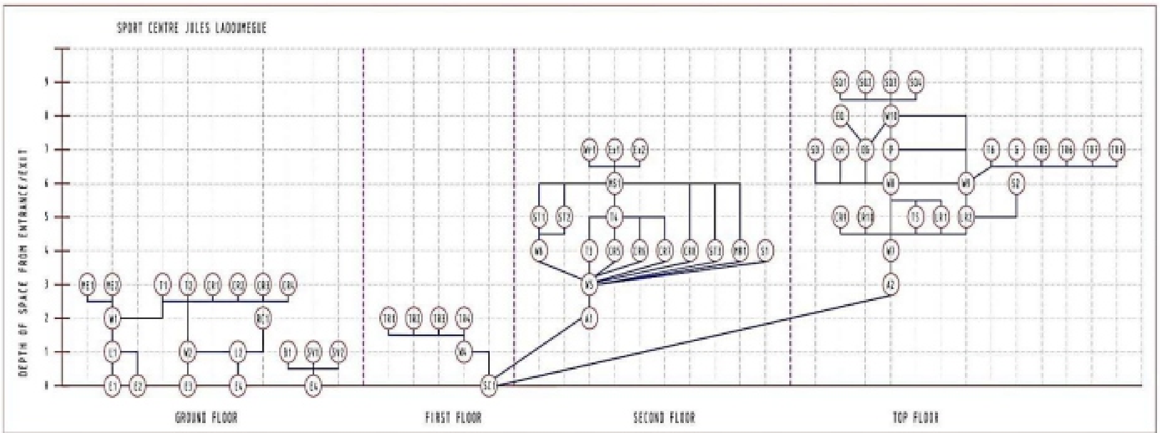

Figure 14: Overall measurable scale graph for Sport Center Jules Ladoumegue

6 Discussion

The analysis sports center is divided into two functions: one for the sports center and another for offices. It shows that Staircase 1 of Sport Center Jules Ladoumegue is the only pathway connecting the ground floor to the top floor. From the overall result of justified graphs of the sports center, the wayfinding is medium. It is not hard to find every space in the sports center. The wayfinding is designed so that every space is linked to other spaces and better control of permeability. Most spaces are located on the second floor and the top floor. From the ground floor, it is the primary level of permeability. The first floor only consists of technical rooms. On the second floor, walkway five and changing rooms are the secondary level of permeability while on the top floor, walkway seven, locker rooms, clubhouse, and changing rooms are the tertiary level of permeability. Patio, dance gymnastics, and squash are the highest level of the sports center's permeability.

The overall office justified graph shows that it is for staff only. It is easy to access and has direct wayfinding. The level of permeability for the office is up to level 4. There is two access either from foyer 1 or foyer 2. This foyer 1 and 2 links to the first floor where space is private. The level of wayfinding for the office is easy and direct. It is easy for people to understand.

Table 5: Summarized permeability of Sports Center Jules Ladoumegue, France

Element	Very easy	Easy	Neutral	Hard	Very Hard
Ground Floor		✓			
First Floor	✓				
Second Floor			✓		
Top Floor			✓		

7 Conclusion

Sports Center Jules Ladoumegue is a public building that provides a place for the public to play sports and live a healthy lifestyle. This study concludes that it answers this research's objective where the space syntax and level of permeability are understood now. The building typology for this Sport Center Jules Ladoumegue is separated into two parts which are the public space and private space. The overall space syntax of this Sport Center Jules Ladoumegue is considered publicand satisfactory. The level of permeability for the public spaces is higher as several spaces are connected. To reach the highest permeability, ones need to go through different spaces. The overall wayfinding for this building is neutral. This sports center visitors can find their way to each space without lost as it is designed from one medium to another medium.

This case study helps to understand how sports centers are designed. It shows the level of permeability from the entrance to the highest permeability. The Space of Accommodations divides every floor with different functions, which is good for separating the users. The spaces are arranged to correspond to its function and are easily find by the visitors. Although the spaces are arranged correspondingly to the sports center's function, the level of permeability is a little bit depth. For visitors to find the squash court, they need to go up to the third floor, go through spaces before reaching the squash court, and confuse visitors as they enter several spaces before reaching the court.

8 Availability of Data and Material

Information related to this work is present in this research paper.

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