Digital technology applications on indoor environment quality

A Research Thesis presented in partial fulfilment of the requirements for the degree of

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I would like to express my gratitude to Zhenan Feng

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STATEMENT OF ORIGINALITY:

Title: Digital technology applications on indoor environment

This is my work, and to my knowledge, I have referenced all material I did not produce.

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Digital technology applications on indoor environment

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Disclaimer – All reports have been submitted as partial fulfilment for the project requirement for the Master of Construction degree.

Abstract

Under the background of understanding various digital technologies, the aim of this research is to investigate the current application of digital technology in indoor environment quality. Indoor environment quality is closely related to residents' health. In modern times, digital technologies have become more sophisticated and widely used. But research on the application of digital technology to indoor environment quality is relatively limited. This research examines the results using a systematic literature review to develop a conceptual framework around the current digital technology situation, indoor environment factors that can be affected by digital technology, and digital technology application methods. This research has proven that 7 digital technologies, such as BIM, IoT, AR, VR, smart sensor, tridimensional laser scanning, and HDRI can be used to monitor, control, evaluate building performance, and assess occupant preferences in relation to indoor air quality, indoor thermal comfort, and other factors related to indoor environment quality. Moreover, it has contributed to providing convenient monitoring, maintaining the room in a healthy environment in real-time, as a reference for designers to achieve an optimal design, and so forth. However, the negative factors such as the cost of digital technology and energy consumption are not mentioned in this research, and the types of indoor spaces involved are also relatively wide, which are the limitations.

1.0 Introduction

Nowadays, with the development of building technology, occupants have been paying more attention to indoor environment quality. Indoor environment quality is closely related to the enjoyment, comfort, health and safety, life quality, and well-being of occupants. According to Sarigiannis (2013), people spend about 90% of their time in an indoor environment each day. An acceptable indoor environment quality can make occupants healthy, keep occupants in high spirits, and improve work efficiency. It is proven in the literature that thermal discomfort and poor indoor air quality can have a significant impact on job performance (Wargocki, 2019). When people are working in an office with acceptable ventilation rates, relative humidity, and temperature, their working performance can be significantly improved (Seppanen & Fisk, 2006).

In recent years, digital technology has been developing rapidly and applied to various industries, including the construction industry. For instance, building information modeling (BIM) provides a bridge of commutation among various stakeholders in a construction project, reducing the risk of misunderstanding and loss of information across a building's life cycle (Latiffi, Brahim & Fathi, 2016). Also, augmented reality (AR) and virtual reality (VR) enable realistic visualization applications, improving customer service experience and reducing project disputes and risks (Noghabaei, Heydarian, Balali & Han, 2020). Regarding indoor environment quality, the applications of digital technology have brought several effects to effectively keep indoor environment quality at a comfortable level for occupants. For instance, the Internet of Things (IoT) makes it possible to easily control and monitor the energy consumption in a building. Consequently, occupants can manage their energy use and behavior to improve the indoor environment. It is important to fully understand the perceptions and responses of the occupants in the indoor environment to maintain and manage energy uses to meet occupants' demands. (Yao & Zheng, 2010). The applications of digital technology on indoor environment quality are becoming popular in the literature. However, after searching and reviewing relevant studies, most of the research papers mainly target some factors of indoor environmental quality, introduce less than 3 applications of digital technologies that can affect these factors, and relatively few papers combine various digital technology with many different indoor environmental quality factors, and 14 out of 15 eligible papers belong to this situation. This research aims to fill this knowledge gap by conducting a systematic literature review. This research investigates the current applications of digital technology on indoor environment quality, the contributions brought by such applications, and the benefits received by occupants.

2.0 Research question

Mujeebu (2019) argues that most of the indoor environment quality studies are focusing on on-site data measurement, collection, and occupant evaluation in different types of buildings. Based on that, this research has the following research questions, considering the integration of digital technology:

Q1: What digital technology have been applied on indoor environment quality?

Q2: What indoor environment factors are influenced by these technology?

Q3: How do these technology work on indoor environment quality?

Q4: What do the contributions of these technology apply to indoor environment quality?

3.0 Background

3.1 Indoor environment quality

Indoor environment quality is a general term for the indoor environment because indoor environment quality includes many different aspects. According to Mujeebu (2019), various factors such as indoor air quality (IAQ), lighting, thermal comfort, acoustics, drinking water, ergonomics, and electromagnetic radiation are all considered as part of indoor environment quality (see Figure 1).

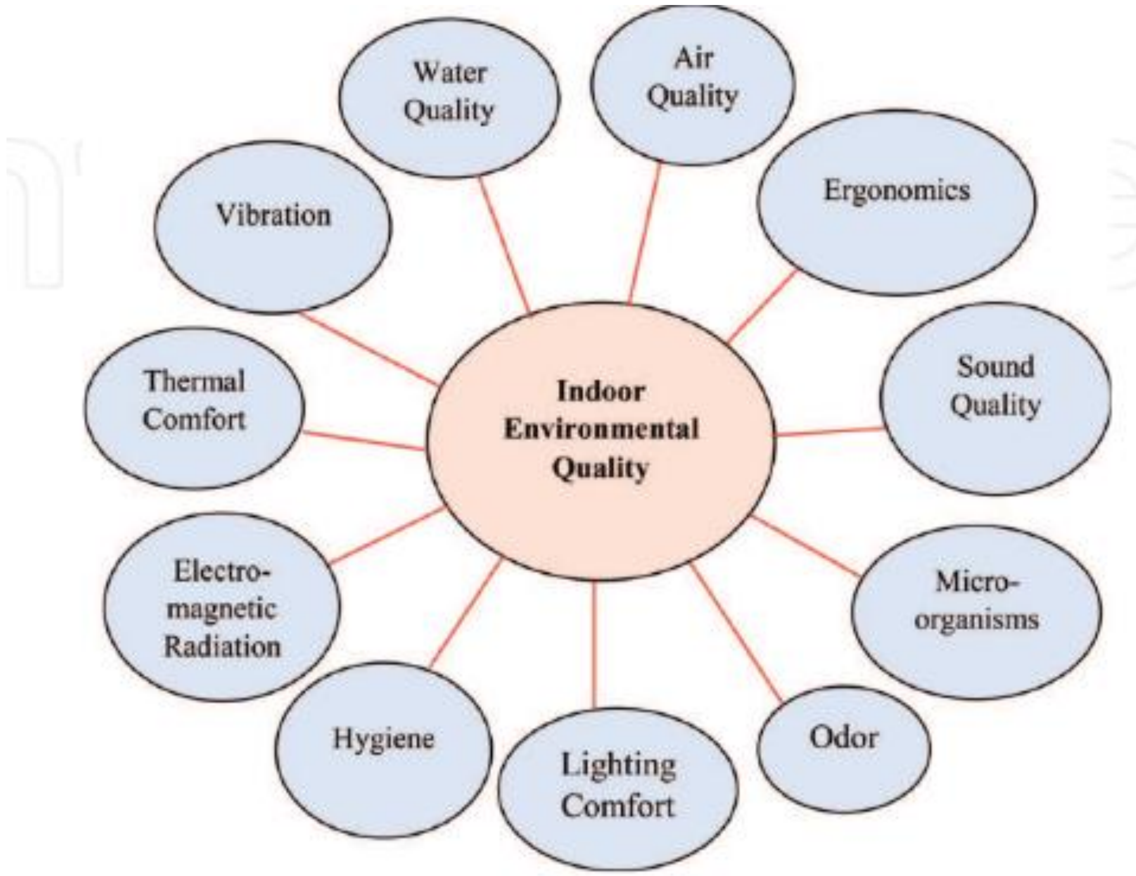

Figure 1 Factors of indoor environment quality. (Mujeebu ,2019)

The indoor environment comfort is highly related to four factors in figure 1, which are indoor air quality, lighting comfort, thermal comfort, acoustics comfort. The indoor thermal, visual and acoustic environment is considered by the World Health Organization to be one of the important factors affecting the health and satisfaction of occupants. (WHO,1990). Also, Indoor air quality is recognized as an important risk factor for human health both in developing and developed countries. (WHO,2006). These four factors are the most subjective factors recognized by occupants.

3.1.1 Indoor air quality

IAQ includes several factors that influence occupants' health, such as the relative humidity, temperature, concentration of volatile organic compounds, and ventilation. There are two types of pollution sources that affect IAQ: the infiltration of outdoor pollutants and the pollution caused by occupants' indoor activities. (Cincinelli & Martellini, 2017). If a house maintains an acceptable IAQ level, it is helpful to keep occupants healthy. However, the negative impact of poor IAQ is serious. Ng, Musser, Persily, and Emmerich (2012) state that lung cancer (due to radon), Legionnaires' disease, carbon monoxide poisoning, allergy, and asthma are among the serious health implications of poor IAQ. Moreover, undesired IAQ provides an environment for mold growth. When mold spores land on a damp spot indoors, they may begin growing and digesting whatever they are growing on in order to survive (Scaringe, 2016). Mold indoors can also affect the health of occupants, in severe cases, it may cause allergy, infection, and toxicity (Kelman, Stock & Robbins, 2020). Many organizations and institutions have put forward recommendations for IAQ. For example, for indoor relative humidity, a Heating, Ventilation, and Air Conditioning (HVAC) system must be able to maintain a humidity ratio equal to or lower than 0.012, and indoor relative humidity is recommended to be lower than 65%. (ASHRAE Technical FAQ, n.d.). Alliance for Environmental Technology suggests that the acceptable indoor relative humidity range is 30% to 50% during winter and 40% to 65% during summer. (Accredited Environmental Technologies, 2010).

3.1.2 Thermal comfort

According to Jenkins (2020) noted, ASHRAE Standard 55-2013 stated that thermal comfort is the condition of the mind that expresses satisfaction with thermal environment. The thermal comfort of occupants depends on individual thermal adaptation. A thermal adaptation ability is composed of many factors, such as time, location, age, gender, and race (Quang, He, Knibbs, de Dear & Morawska, 2014). The indoor environment affects the thermal comfort of occupants. Lewis, Steemers, and John (1992) report that the indoor environment consists of radiant temperature, relative humidity, and air velocity. The design process will take these factors into account. Figure 2 shows the predicted mean vote (PMV) scale of indoor thermal comfort from ASHRAE standard 55-2013. The recommended value of PMV for thermal comfort is from -0.5 to 0.5. (Cubick, 2017).

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
−1	Slightly cool
−2	Cool
−3	Cold

Figure 2The mean PMV scale.(Cubick, 2017).

3.1.3 Acoustic comfort

Acoustic comfort refers to an acoustic environment that makes occupants feel comfortable through the control of indoor acoustic sources (Abdul Mujeebu, 2019). Noise has many effects on occupants, for example, noise may lead to poor quality of sleep, distraction during work or study, or irritability. As a survey made by the Jensen & Arens (2005) states, 40% of employees are dissatisfied with the impact of noise in their office, which jeopardizes the efficiency and productivity of their work. (Jensen & Arens, 2005). In some industries, noise is more common, such as construction sites and heavy production workshops. The people working on these sites are affected by noise generated from their workplaces and infiltrated from the outdoors. An unacceptable acoustic environment affects occupants' health, in research of Kim (2015) stated 16% of adults are suffering from hearing loss due to noise pollution.

3.1.4 Visual comfort

Visual comfort is also called lighting comfort because it is defined as lighting conditions and the views from workspaces. (Al horr et al., 2016). An illuminance is a unit for measuring indoor light levels. Preto and Gomes suggest a few acceptable luminance levels in the different indoor environments. For instance, for the computer industry, the recommended working plane illuminance is 300 lx; for paper-based work, 500 lx illuminances are acceptable; for daily office work, it is recommended to perform under the conditions of 320lx Illuminance level. (Preto & Gomes, 2018). Unacceptable Illuminance levels can affect the health of occupants, leading to eye fatigue, migraines and headaches, drowsiness, irritability and inattention. Additionally, poor lighting is not only detrimental to the health of employees at work, causing symptoms such as eyestrain, migraines, and headaches, but it is also associated with Sick Building Syndrome in newly constructed and renovated buildings. (Great Britain. Health and Safety Executive, 1997).

3.2 Digital technology

Digital technology stores, transmits, processes, and forwards the information in a digital format, which is then applied to computers, electronic devices, or mobile devices (Pullen, 2009). For instance, the applications on smartphones, computers, online gaming are all considered as digital technology. Also, AR, VR, BIM, IoT, big data analytics, artificial intelligence, and cloud computing are all belonged to digital technology. (Khin & Ho, 2019). The goal of the application of digital technology is to facilitate decision-making and improve the management quality of projects. (Aleksandrova, Vinogradova & Tokunova, 2019).

In today's society, the application of digital technology is emerging and becoming important in various industries. According to a survey conducted by Fitzgerald (2013), 78% of respondents believe that the company's transition to digital technology will be crucial in the next two years, and it will also be a trend in all industries in the future, 38% of respondents believe that digital technology is a permanent task of the company, and among companies that adopt digital technology, 93% think it is correct for the organization.

Digital technology is rapidly reshaping the construction industry. Digital technology breaks the boundaries between physical, digital, and biological entities, establishing the connection among them. Technological breakthroughs have found new ways to demonstrate their capabilities. (Alaloul, Liew, Zawawi & Kennedy, 2020). A study shows that the digital construction industry has achieved a certain degree of development. (Aghimien, Aigbavboa, Oke & Koloko, 2018). They found that digital technology has the highest application rate in the feasibility study phase and the design phase of a construction project. Digitalization has effects on improving productivity, efficiency, documentation quality, communication, and collaboration. (Aghimien, Aigbavboa, Oke & Koloko, 2018).

The research focusing on the application of digital technology in a built environment is becoming popular. However, an overview understanding of the application of digital technology on indoor environment quality is still lacking in the literature.

4.0 Method

This research aims to investigate the current application of digital technology on building indoor environment quality. In order to achieve this research aim, this research adopts a systematic literature review approach to conduct qualitative data analysis. A systematic review is a comprehensive collection of all relevant studies, a rigorous evaluation of the included studies one by one, a comprehensive analysis and evaluation of the results of all studies, and a comprehensive conclusion to provide scientifically. This systematic literature review was conducted following a framework that is divided into five steps, including formulating the research question, identifying relevant work, assessing the quality of studies, summarizing the evidence, and interpreting the findings (Khan, Kunz, Kleijnen & Antes, 2003).

5.0 Data analysis

5.1 Identifying the relevant work

After searching for various related studies, Wehbe and Shahrour (2019) show that both smart sensor and BIM can be used as digital technologies that affect indoor comfort. Additionally, Nogarede and Stostad (2020) stated that the role of virtual reality and augmented reality indoors involves the collection of sensitive data about people's behavior, sound, and environment, which are related to indoor environment quality. IoT is considered to be one of the most important factors in the development of smart home trends today, and IoT is the biggest and most exciting trend in smart home trends. (Pankaj, 2022).

Three databases were considered to search for target literature: ResearchGate, Scopus, and Google Scholar. The eligible literature must cover three major concepts, namely the application of digital technology, indoor environment quality factors, and the contributions of digital technology to indoor environment quality. Based on the four research questions, the following searching keywords were formulated: 'digital technology' or 'smart sensors' or 'virtual reality' or 'VR' or 'augmented reality' or 'AR' or 'building information modeling' or 'BIM' or 'internet of things' or 'IoT' and 'indoor air quality' or 'indoor environment quality' or ‘thermal’ or ‘acoustics’ or ‘light’. The searching keywords take synonyms into consideration. No restrictions on publication time and language were applied. A total of 291 papers were found after searching, including 100 from ResearchGate, 2 from Google Scholar, and 189 from Scopus (see Figure 3).

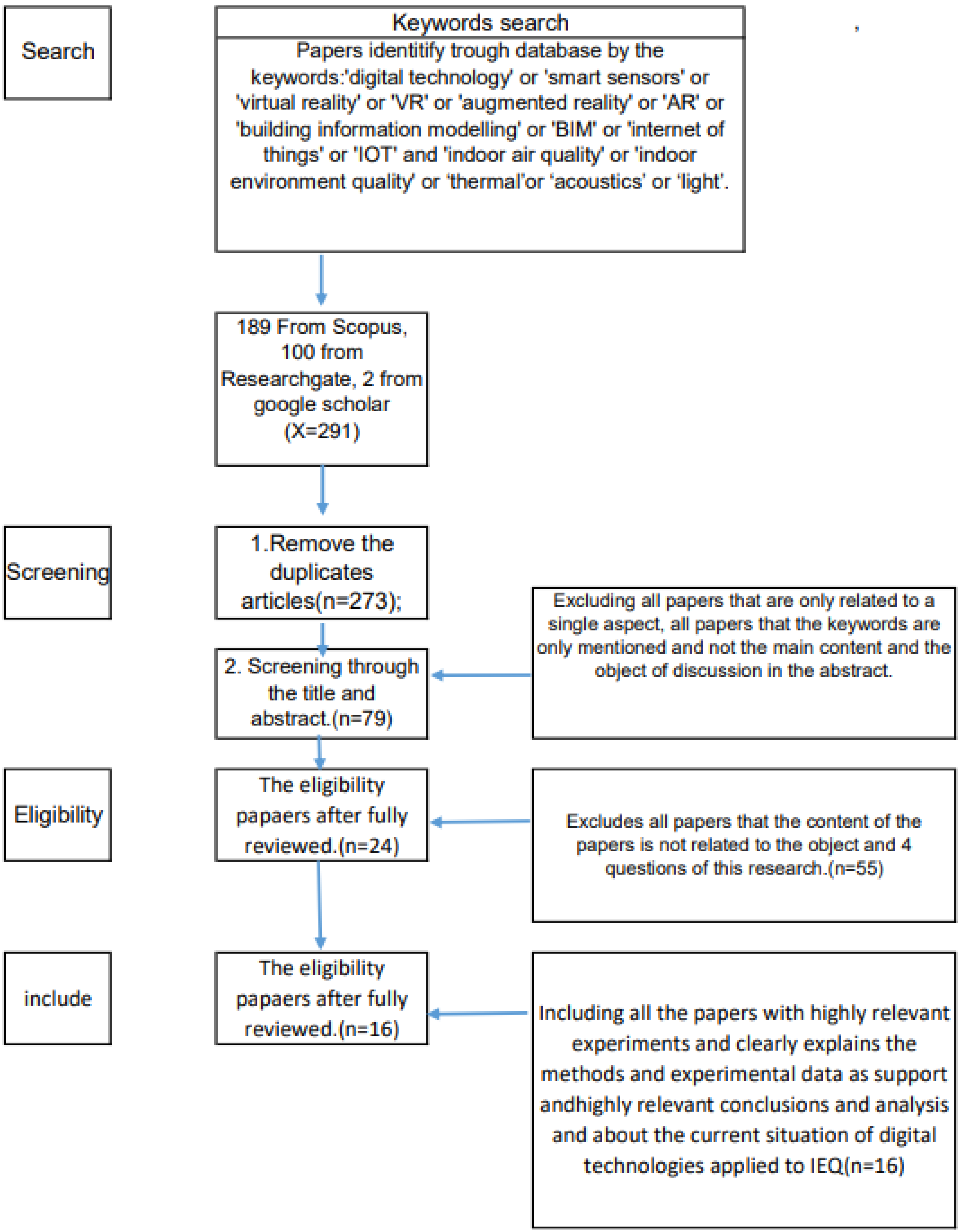

Figure 3 Study selection process

After removing duplicates, 273 papers were left. Next, a screen stage took place, which focused on the titles and abstracts of the 273 papers. Papers covering both digital technology and indoor environment quality concepts were kept in the screening stage.

Papers were excluded if none or a single concept was mentioned in the abstract. After screening, 79 papers have remained for full-paper check. The inclusion criteria for full-paper check includes:

1. Papers provide highly relevant experiments, explain detailed methods, discuss experimental results, and conduct data analysis.

2. Papers discuss the current situation of digital technology applied to indoor environment quality

The full paper check excluded papers if the content of the papers is not related to the four research questions established in Section 3.1.

Finally, 15 papers were identified as eligible papers for this systemic literature review (Aswin, Adhiyaman & Mary Posonia, 2018), (Birgonul, 2021), (Chiou, Saputro & Sari, 2020,Esquiagola), (Manini, Aikawa, Yoshioka & Zuffo, 2018),(Ha, Metia & Phung, 2020), (Jo, Jo, Kim, Kim & Han, 2020, Lee & Nik-Bakht, 2019), (Lu & Warsinger, 2020, Marques et al., 2020), (Natephra & Motamedi, 2019), (Pangestu, Yusro, Djatmiko & Jaenul, 2020),(Rodrigue, Demers & Parsaee, 2020), (Rosenlund, Li & Petersen, 2018), (Salimi & Hammad, 2019), (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020.) There are 2 eligible papers were published in 2018, 3 papers in 2019, 8 papers in 2020 and 1 published in 2021.

5.2 Assessing the quality of studies

The purpose of this part is to evaluate the relevance of the 15 eligible papers against research questions. Connolly et al. (2012) used a method for assessing the quality of studies by providing unified several evaluation standards for the papers and scoring the quality in accordance with these standards. Refer to this method, this paper provided two questions to score each eligible paper:

1. How relevant is the paper to the four research questions of this research?
2. To what extend can the paper answer the four research questions of this research?

The scores for each question range from 1 to 3, with 1 stands for low relevance and 3 means for high relevance. As a result, the possible score for each paper ranges from 2 to 6. Figure 4 shows the final scores of the eligible papers.

The average score of these 15 eligible papers is 4.6667; the overall standard deviation is 0.9822; and the variance of the overall standard deviation is 0.9648. The detailed scoring results are attached as Appendix 1, including the titles, authors, years, and scores of each eligible paper.

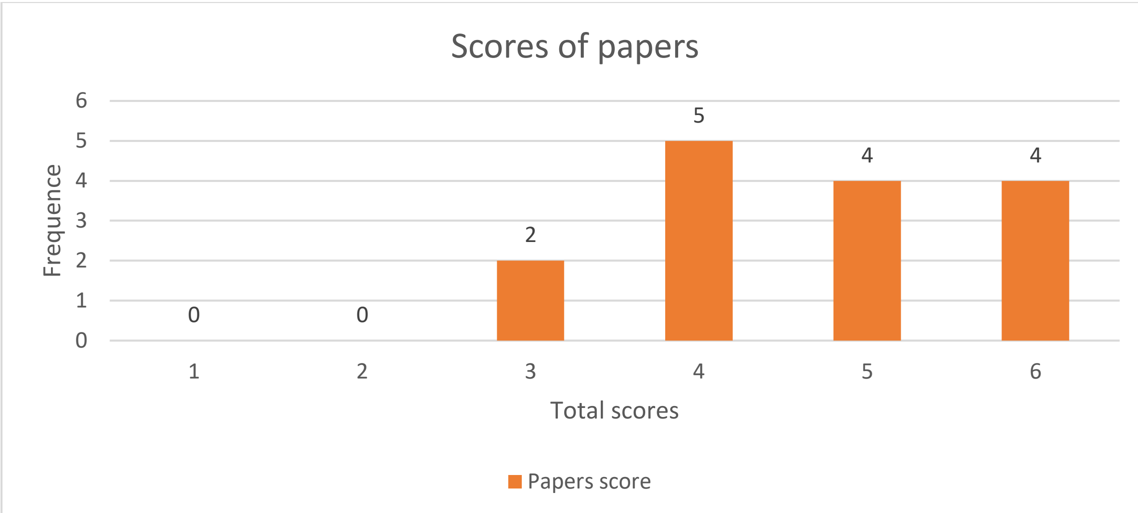

Figure 4 Scores of each paper

6.0 Result

This part will be based on the four main questions. An analysis is conducted by using a spreadsheet to extract relevant data from eligible papers.

6.1 Digital technology

Table 1 identifies 9 different digital technologies that can apply to indoor environment quality based on question 1. Which are BIM, AR, IoT, smart sensor, Convolution neural networks, VR, Tridimensional laser scanning, Radiant Systems, and High dynamic range image. Out of these eligible papers, one summarizes BIM, IoT, and AR, one includes BIM and IOT, and two discuss IoT and smart sensors.

Digital technology Factors	**Characteristic**
Building information modelling (Birgonul, 2021); (Lee, J., & Nik-Bakht, M. 2019) (Natephra & Motamedi,	1.Visualization of data flow; 2.Information collection, capture and storage; 3.Interoperability; 4.'Dynamic information' restriction 5.Immature interoperability

2019); (Salimi & Hammad,2018)	
Augmented reality (Aswin, Adhiyaman & Mary Posonia, 2018); (Natephra & Motamedi, 2019)	1.Data and information interoperability; 2.Data visualization; 3.Compatible with any platform or device
Internet of things (Jo, Jo, Kim, Kim & Han, 2020); (Lu & Warsinger, 2020); (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020); (Marques et al., 2020); (Natephra & Motamedi, 2019); (Esquiagola, Manini, Aikawa, Yoshioka & Zuffo, 2018); (Salimi & Hammad); (Pangestu, Yusro, Djatmiko & Jaenul, 2020)	1.Sensing, management and monitoring; 2.Cloud function; 3.Interoperability; 4.Time and cost for deploy
Smart sensor (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020); (Ha, Metia & Phung, 2020)	1.Predict variables; 2.Make control smart; 3.Performance of different type; 4.High Dependence
Virtual Reality (Rosenlund, Li & Petersen, 2018)	1.Realistic scene simulation
Tridimensional laser scanning (Rodrigue, Demers & Parsaee, 2020)	1.High-quality 3D models 2.More detailed data; 3.High cost 4.Not applicable to all space types; 5.External condition effect
High dynamic range Image (Chiou, Saputro & Sari, 2020); (Rodrigue, Demers & Parsaee, 2020)	1.High- quality measurement 2.Wide use, accuracy and repeatability; 3.Constrained by space 4.External factor effect data collection

Table 1 The summary of digital technologies from eligible paper

6.1.1 BIM

4 of the 16 eligible papers mainly discuss the application of BIM to indoor environment quality. (Birgonul, 2021; Lee, J., & Nik-Bakht, M. 2019; Salimi & Hammad,2018; Natephra & Motamedi, 2019).

These papers identify the reasons and advantages of BIM as applied to indoor environment quality. BIM provides data collection and data transfer in a visual and transparent nature so that it is compatible with other digital technologies and combined applications.

Birgonul (2021) and Salimi & Hammad (2018) all mentioned the characteristics of information and data collection in BIM in the literature. BIM establishes data collection and creates a system for sustainable information collection, and Salimi & Hammad pointed out that BIM is a shared digital representation of buildings. BIM basically hosts a database of information embedded in spatial objects, BIM provides information by combining reality capture and real data to generate building and environment models, BIM realizes data visualization in the form of models and can be transparently circulated to different users. (Birgonul, 2021; Salimi & Hammad, 2018).

These papers also emphasize the importance of BIM information and data interoperability. As Birgonul (2020) pointed out, BIM's interdisciplinary information sharing can also be defined as interoperability. Three papers illustrate this advantage, including the combination of BIM and IOT and the integration of BIM in BMS. (Salimi & Hammad, 2018). And the integration of BIM with IoT and AR (Natephra & Motamedi, 2019). The IoT is also considered as a kind of interconnection of sensing and actuating devices and a digital technology that provides the ability to share information across platforms through a unified framework. IoT-BIM covers a wide range of fields, including facilities management, building flow and management, health and safety management, and building operation and monitoring. (Birgonul, 2020). In addition, Natephra and Motamedi (2019) explained the working process of the combination of BIM, IoT, and AR. Sensors capture and collect data, which is then transmitted and stored in the BIM model, as well as visualized with BIM and AR. (Natephra & Motamedi, 2019). As an example, IOT also plays a role in collecting data, and presenting visualized data through BIM, and then displaying the data in BMS to make decisions. (Salimi & Hammad, 2018).

However, the limitation faced by BIM is ‘dynamic information’, that is, the model can be dynamically adjusted with the dynamic information transmitted in real-time. Moreover, in the current technology and software applications, the combination of BIM and IoT for real-time building data collection is still in its infancy and future research is required. (Birgonul, 2020). As Lee, J., and Nik-Bakht, M. (2019) stated, most existing IoT deployments cannot benefit from BIM's rich digital representation and its graphical visualization capabilities. (Lee, J., & Nik-Bakht, M. 2019).

6.1.2 Augmented reality

Both Aswin, Adhiyaman & Mary Posonia (2018) and Natephra & Motamedi (2019) studied the application of AR to indoor environment quality. Firstly, both papers mentioned the characteristics of data and information interoperability in AR technology. Moreover, AR can realize static data visualization. Thirdly, AR can be applied to a variety of devices to perform certain functions.

Using AR technology, virtual objects can be placed in the real world by using digital information. Data visualization in a 3D model is one of its characteristics. AR can also be used for interoperable information and measurement data if combined used with sensing data sources. (Aswin, Adhiyaman & Mary Posonia, 2018). Natephra & Motamedi (2019) also discussed AR's ability to visualize static data, as well as its interoperability. The paper introduces a method of integrating BIM, IoT, and AR. In this combination, AR serves as a display of visualized data. Moreover, the advantages of data visualization of AR technology help stakeholders to easier understand the output of the sensor. (Natephra & Motamedi, 2019).

AR is also compatible with various devices and platforms, and commercial applications have been developed. (Natephra & Motamedi, 2019). For example, as introduced by Aswin, Adhiyaman & Mary Posonia (2018), the visualization of data is realized through Unity 3D on the computer. The research of Natephra & Motamedi (2019) noted that AR was applied on an Android smartphone, using the unreal engine application to achieve the expected performance. which is more convenient, without location restrictions, and more flexible.

6.1.3 Internet of things

There is eight eligible literature address the IoT apply on indoor environment quality.(Jo, Jo, Kim, Kim & Han, 2020; Lu & Warsinger, 2020; Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020; Marques et al., 2020; Natephra & Motamedi, 2019; Yoshioka & Zuffo, 2018; Salimi & Hammad, 2019). In summary, most papers indicated the same characteristics of IoT are sensing, management, and monitoring. In addition, there are three papers that discuss the cloud function of IoT. (Jo, Jo, Kim, Kim & Han, 2020; Yoshioka & Zuffo, 2018; Salimi & Hammad,2019). The automation and interactivity features of the IoT are also mentioned. (Marques et al., 2020; Yoshioka & Zuffo, 2018; Salimi & Hammad, 2019). Lu & Warsinger also mentioned the limitation of IoT, which is the cost of deployment. (Lu & Warsinger, 2020).

IoT can be used as the basis of sensors for real-time data monitoring and management. (Jo, Jo, Kim, Kim & Han, 2020; Natephra & Motamedi, 2019; Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020). According to Marques et al (2020), with the support of IoT, the device can be processed through an identifiable address, provide collaboration functions and provide ubiquitous universal applications, as well as provide for remote monitoring and data consultation from anywhere and at any time. Salimi & Hammad (2019) mentioned that the IoTs provide the advantage of near-real-time continuous data collection and process and analysis of the data. The IoT is monitored through the Internet, and remote monitoring can also be implemented through a device like a smartphone. (Pangestu, Yusro, Djatmiko & Jaenul, 2020).

In addition, the 'cloud' function of the IoT is also mentioned in most eligible papers. Jo, Jo, Kim, Kim & Han (2020) proposed an IoT monitoring platform based on the integration of cloud computing and IoT. IoT and cloud computing can achieve real-time monitoring. Yoshioka & Zuffo (2018) define the IoT as a wireless sensor network with a specific Internet interface that can deploy information over the cloud. Also, computing at the edge of the networked structure is one of the latest types of sensory data processing that can communicate with other systems via cloud computing or edge computing. Edge processing can overcome the latency and other problems that come from using centralized cloud computing. (Salimi & Hammad, 2019). The interactivity of IoT is an advantage. (Natephra & Motamedi, 2019 ;Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020; Yoshioka & Zuffo, 2018; Salimi & Hammad, 2019). Yoshioka & Zuffo (2018) mentioned that IoT applications can be packaged in RESTful Web services. According to Natephra and Motamedi (2019), the interaction of IoT with real-time sensing technology enables it to be applied to various platforms, as well as allowing data streamed by the IoT from network-connected devices to be converted into other forms of data. Salami & Hammad (2019) explained that the collected data is transferred to the actuator through an adaptive operating system that utilizes a combination of IoT-BMSs to implement different decisions and controls. And the interactivity of IoT also promotes the sharing of information. By providing better communication and data exchange between sensing and control systems, through the application of the IoT, data collected from different sources can be shared and used for different purposes.

Lu & Warsinger (2020) indicate that although IoT enables indoor data to be effectively collected and analyzed by data collectors, it also requires a substantial amount of installation time and cost to apply to a home.

6.1.4 Smart sensor

There are 2 papers mainly related to the smart sensor. (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020; Ha, Metia & Phung, 2020).

Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan (2020) describe that one of the advantages is the ability to predict variables, as well as the possibility of creating models for unmeasured variables. The soft sensor also enhances the control's intelligence. The measurement results are converted into digital values and transmitted to the control unit.

As mentioned by Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan (2020) as well as Ha, Metia & Phung (2020), the different sensors will affect the results of measurements. For example, cheap sensors, reliability, and performance will be limited. Moreover, Ha, Metia, and Phung (2020) found that using sensors as the sole data collection tool will lead to reliance on the sensors, lack of data measurement, and possible deviations in data processing, thereby affecting the accuracy of the final results.

6.1.5 Virtual reality

Rosenlund, Li & Petersen (2018) noted that VR is the main function of scene simulation, presenting different indoor situations in the VR environment. Immersive VR simplifies the setting and arrangement of venues with different environment requirements and combines the real situation to control the variables, facilitating participants to make decisions.

6.1.6 Tridimensional laser scanning

The primary advantage of tridimensional laser scanning is its powerful 3D modeling function. Rodrigue, Demers & Parsaee (2020) state that the modeling is created by aligning and fusing several scans, which can capture huge complex geometric spaces, even surface colors, enabling data collectors to gain a deeper understanding of the scan space. Moreover, based on the collected data, the intensity value from the laser scanner can be used to determine the importance of each surface, its reflectivity, and its anisotropy.Due to the relatively high cost of 3D laser scanning, this technology is not economically viable for small spaces or the space of a simple structure and cannot fully reflect the effect. Changes in external environment conditions during the capture process of 3D laser scanning will cause inaccurate pattern representation. (Rodrigue, Demers & Parsaee, 2020).

6.1.7 High dynamic range image

There are two papers that studied the high dynamic range (HDR). (Rodrigue, Demers & Parsaee, 2020; Chiou, Saputro & Sari, 2020). In summary, the meticulous degree of HDR measurement is an advantage, and its wide use is also mentioned. However, the disadvantage of HDR is that it is constrained by space, and external factors will further cause it to be incomprehensible in analyzing and collecting data.

Both Rodrigue, Demers & Parsaee, (2020) and Chiou, Saputro & Sari, (2020) agree with the superiority of HDR measurement data. HDR fisheye images have been used for data collection and analysis from a human-accessible perspective. Also, HDR can now measure the spatial distribution of brightness. HDR has the advantages of wide use, accuracy, and repeatability. (Rodrigue, Demers & Parsaee, 2020)

However, Chiou, Saputro & Sari, (2020) pointed out, the quality of the data will be affected due to external factors, such as shaking may cause blurred images. In addition, the physics of space has an impact on HDR, HDR will not be able to be used in large or complicated spaces. Furthermore, changes in the complexity of target size and geometry will also complicate the understanding and expression of the overall interaction between the light source and the surface, preventing HDR from fully understanding the light source and its physical environment as well as the interaction between them. (Rodrigue, Demers & Parsaee, 2020).

6.2 Indoor environment quality

Table 2 identifies 5 different indoor environment quality factors that can be influenced by digital technology based on question 2. Which is thermal comfort, acoustic comfort, IAQ, visual comfort.

Indoor environment quality factors	Simple description
Thermal comfort (Birgonul, 2021)； (Lu & Warsinger, 2020)； (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020)； (Natephra & Motamedi, 2019)； (Ha, Metia & Phung, 2020)； (Salimi & Hammad, 2019)； (Rosenlund, Li & Petersen, 2018);	Factors affecting the perception of occupants' thermal comfort include room geographic conditions, room's own conditions, weather, IAQ, occupants' personal factors, and so on.
Acoustic comfort (Lee & Nik-Bakht, 2019)	The recommendation by standard, the factors that affect the acoustic performance in a house.
Indoor air quality (Jo, Jo, Kim, Kim & Han, 2020); (Marques et al,2020;) (Manini, Aikawa, Yoshioka & Zuffo, 2018); (Ha, Metia & Phung, 2020)； (Pangestu, Yusro, Djatmiko & Jaenul, 2020); (Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020);	The sources that impact IAQ; The dangerous and importance of IAQ for occupants
Visual comfort (Chiou, Saputro & Sari, 2020); (Salimi & Hammad, 2019); (Rodrigue, Demers & Parsaee, 2020);	How light affects the visual comfort of occupants

Table 2 The summary of indoor environment quality factors from eligible papers

6.2.1 Thermal comfort

A total of 7 eligible papers mentioned the characteristics related to thermal comfort. (Birgonul, 2021; Lu & Warsinger, 2020; Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020; Natephra & Motamedi, 2019; Ha, Metia & Phung, 2020; Salimi & Hammad, 2020).

Birgonul, (2021) presents a variety of thermal comfort elements that will produce different perceptions of thermal comfort to people who are indoors. Included is the surrounding environment, the building location, the quality of the space, the materials of the building, the weather, and the indoor temperature. Additionally, thermal comfort is also influenced by the personal factors of the indoor individual. The type of indoor activity and whether it is intense, and the clothing all affect the perception of thermal comfort. Also, Lu and Warsinger (2020) demonstrate that rooms can receive different levels of solar heat gain through windows of different sizes and orientations, which results in people with different thermal comfort preferences using different rooms at different times of the day.

Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan (2020), Ha, Metia & Phung (2020), as well as Rosenlund, Li & Petersen (2018) discussed the IAQ factors that have an effect on indoor thermal comfort. For example, a change in relative humidity limits thermal comfort, and increased indoor and outdoor air circulation decreases thermal comfort. What's more, Rosenlund, Li & Petersen (2018) proposed that the color of the room can also affect the perception of thermal comfort.

6.2.2 Acoustic comfort

Lee & Nik-Bakht (2019) pointed out that the indoor acoustic condition highly relates to the acoustic perception and performance of occupants. ANSI/ASA S12.60-2010 recommended evaluating acoustic performance in a building. The reverberation time is 0.6s in a 283 m^3 hermetic area, for a broader area, the 0.7s of reverberation time is acceptable.

Also, the acoustic performance of a building is related to the building materials. Acoustic comfort will be affected by the absorption coefficient and scattering coefficient of the surface finishing materials. The secondary surfaces in a building affect the acoustic performance as well, for instance, furniture, windows, and doors.

6.2.3 Indoor air quality

There are seven papers eligible to be reviewed for the content about IAQ. (Jo, Jo, Kim, Kim & Han, 2020; Marques et al,2020; Pangestu, Yusro, Djatmiko & Jaenul, 2020, Manini, Aikawa, Yoshioka & Zuffo, 2018, Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, 2020; Aswin, Adhiyaman & Mary Posonia, 2018, Ha, Metia & Phung, 2020).

IAQ is a collective term for many elements. Manini, Aikawa, Yoshioka & Zuffo, (2018), Pangestu, Yusro, Djatmiko & Jaenul, (2020), Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan, (2020) have described that aerosols, temperature, relative humidity, particulate matter in the air, and volatile organic compounds, fungi or bacteria, carbon dioxide concentration, and ventilation in a building are all sources that determine whether IAQ is acceptable. The main source of pollution of IAQ was also summarized as paint and other household chemicals, tobacco smoke, number of people living in buildings, the time spent indoors, furniture, outdoor air pollutants, occupant activities, and so on (Aswin, Adhiyaman & Mary Posonia, 2018; Ha, Metia & Phung, 2020).

Jo, Jo, Kim, Kim & Han (2020) and Marques et al (2020) indicate that the United States Environment Protection Agency notes that indoor air takes more time in the day than outdoor air to circulate and affects the health of the occupants. The pollution level of IAQ is approximately 100 times that of outdoor air and the possibility of indoor air pollutants spreading to the lungs is even about 1,000 times higher than outdoor air pollutants, which may cause occupants to suffer from sick building syndromes such as respiratory diseases. According to Pangestu, Yusro, Djatmiko & Jaenul (2020), airborne particles accumulate in the eyes of occupants or on metal objects in the room, resulting in dry eyes and metal corrosion. The dangers of poor air quality can be compared to tobacco and sexually transmitted diseases, poor IAQ has serious negative effects on the elderly, children, and sensitive persons, the air quality concentration level causes 3.2 million deaths pre-year, about 60,000 people in the United States died prematurely because of the decline in air quality, and in 2016, about 400,000 people died prematurely in EU countries.

6.2.4 Visual comfort

Visual comfort is closely related to indoor lighting in the workplace. Light may produce glare, reflection, and different contrasts in the eyes of occupants. The visual comfort of occupants is affected by the amount of indoor light and illuminance. According to Rodrigue, Demers & Parsaee (2020), examining the relative illuminance of light in a certain range of space can help identify whether there is a lack or an even distribution of light on a certain surface.

6.3 The application of digital technology on indoor environment quality and the contributions

There are four methods of digital technology being applied to indoor environment quality, namely: (1) Monitoring, (2) Control, (3) Building performance evaluation, (4) Occupants indoor environment quality preference test.

6.3.1 Monitoring

Lee, J., & Nik-Bakht, M (2019) integrated BIM technology and AR to achieve visual monitoring of IAQ. This process is to create a virtual model on Revit 2017 and place Arduino Uno and its compatible sensors in the room to be tested to continuously collect indoor temperature, relative humidity, and light intensity in different spaces. The data will be transmitted through a software program developed by Dynamo, which will be stored automatically in the BIM model. As soon as the sensors are connected to the pre-created game environment, the data from Revit is imported into the Unreal Engine, and a virtual chart representing the measurement parameters of the physical environment is created. Finally, the mobile phone is the terminal to realize visualization in an AR environment.

Slightly different, Aswin, Adhiyaman & Mary Posonia (2018), Jo, Jo, Kim, Kim & Han, (2020), Ha, Metia & Phung (2020), and Manini, Aikawa, Yoshioka & Zuffo (2018) applied the IoT to monitoring. According to the process, data is collected and transmitted to the cloud through IoT sensors, analyzed and calculated in the cloud, and then feed the results back to the presentation terminal to achieve accurate location and time air quality monitoring. Aswin, Adhiyaman & Mary Posonia (2018) noted that these sensors are connected to GPS to determine the precise location of the device. Data from these sensors is then uploaded to a public cloud environment. The collected data is transmitted through the microcontroller and updated in real-time in the Cloud environment. Data is stored in the cloud, and then Vuforia and Unit 3D are integrated to perform front-end processing of the data, creating images, and so on, then finally, the collected data on each room is displayed through the AR platform, which provides a real-time remote access capability. Jo, Jo, Kim, Kim & Han (2020) Use Long-Term Evolution to transmit the data collected by the 'Smart-air' sensor to the cloud, record these data in real-time in the Cloud computing-based Web Server, and then return these data to the mobile phone application for visual monitoring.

A portable air quality monitoring equipment concept was proposed by Marques et al. (2020) based on the application of IoT to IAQ. Air monitoring equipment primarily consists of two main components, including the ESP32 microcontroller that supports Wifi, BLE, and LoRa communication. This controller performs data analysis through mobile computing technology and sends it to the terminal (smartphone) by BLE. The second part is the DFRobot Co2 sensor, with its primary function being to measure and map carbon dioxide concentration in real-time. The application on the mobile phone can locate based upon the GPS function and will output the measurement results along with the location of the measurements. The data will then be transmitted via the Webserver to the MS SQL Server database for storage. Manini, Aikawa, Yoshioka & Zuffo (2018) apply gateways, border routers, and MariaDB databases to process, transmit, and store data collected from sensors.

6.3.2 Control

It is a direct method of controlling the indoor environment that the occupants adjust according to their comfort level. It is necessary to collect and accumulate data pertaining to indoor environment quality, so that the occupants can make appropriate adjustments through the console in response to the real-time data and their personal experiences. According to Birgonul (2021), the SDP platform was developed as a receiving response tool to identify thermal mass and surrounding environment in real-time and evaluate real-time external weather and internal thermal information. The hardware is a receiver and transmitter (non-contact infrared thermometer MLX 90614). The transmitter needs to be worn by the occupant. The main function is to collect real-time data on the occupant’s ears, core body temperature, and surface temperature of any part of the limbs or skin. And transmit these data to the terminal (receiver), the receiver integrates BIM and Dynamo visual programming language, display real-time thermal comfort data to the occupants, and through the platform's customized algorithm according to the BIM extracted calorific value data, outdoor weather information, real-time ambient indoor temperature, occupant body temperature, and indoor location to create a personalized thermal comfort analysis, and then adjust the thermal comfort according to different indoor conditions, and adjust the HVAC system to manage the indoor temperature to achieve the best thermal comfort. In addition, Salimi & Hammad (2018) mentioned the application of smart sensors to control indoor HAVC systems to optimize indoor ventilation and energy consumption. Since most building control systems operate according to preset regulations, this results in the control system being limited in adjusting building servers according to the indoor occupancy rate, and there is excessive energy consumption. A method of adjusting the HAVC system based on the indoor occupancy rate is proposed, including motion sensors, vision-based localization technology, RF-based localization technology, multi-sensor networks, and virtual occupancy sensors. The application of these occupancy rate monitoring technology is mainly to collect data on the number and location of occupants indoors, as well as the preferences of occupants and their interaction with various energy-related systems in the building. Based on the collected data, an adjustment strategy for the HAVC system is proposed and set in the HAVC system. The sensor sends the collected data and control signals to the HAVC system to realize the adjustment of the HAVC system and achieve the best indoor environment comfort degree and energy consumption. Vadamalraj, Zingre, Seshadhri, Arjunan & Srinivasan (2020) describe a method of controlling air conditioners using IoT to maintain indoor thermal comfort, the IAQ is collected through the DHT11 sensor, and the passive infra-red (PIR) sensor is used to collect the indoor occupancy data. According to the pre-set occupant preference range and indoor occupancy to control the Air-Conditioner to switch between cooling mode and fan mode, then maintain the indoor thermal comfort is controlled within an acceptable range.

Pangestu, Yusro, Djatmiko & Jaenul (2020) introduced a method to control dust concentration, temperature, and relative humidity by hardware and IoT, this method includes infrared-based type GP2Y1010AU0F Optical Dust Sensor and DHT 22 sensor to collect data from indoor area. The Arduino Mega 2560 is a control system that connects the Internet by smartphone web through the router. Then there are 6 output items be set, two indicators applied lamps to present whether dust level and temperature are higher than the threshold of 0.15 mg/m3 and 35℃ which are recommended by Decree No. MENKLH No. Kep.02 / MENKLH / 1988. And a buzzer that will sound if the values are exceeded, then using exhaust fans and sprayer to neutralize the temperature and dust to the normal level, and the data will be displayed through LCD to the mobile web.

6.3.3 Building performance evaluation

Lee & Nik-Bakht (2019) have developed a method to assess a house's acoustic comfort performance using the characteristics of BIM visualization. This method is mainly based on simulation testing and calculating the reverberation time using Revit. The simulation process is implemented in Dynamo and passed Revit access. Figure 5 illustrates Sabine's formula for calculating reverberation time. The calculation of reverberation time includes 10 modules, which are the calculation of room area, floor and ceiling area calculation, ceiling finishing materials, Floor & Ceiling (Material–Area) Matrix, Wall's Finishes (Material–Area) Matrix, and room. The volume calculation of the OpenMat database involves the absorption coefficient of the corresponding material, matching the material and calculating the reverberation time, and assigning values to parameters reverberation time. The process is shown in figure 6. Finally, the calculation results create a view representing a reverberation time for each module on each floor in Revit and mark them with different colors as symbols according to the range of the highest and lowest reverberation time in the room to achieve an intuitive visual room acoustic performance evaluation model.

$$RT_{60} = \frac{0.161\,V}{\sum S\alpha}$$

Figure 5 Sabine’s formula of reverberation time.(Lee & Nik-Bakht ,2019)

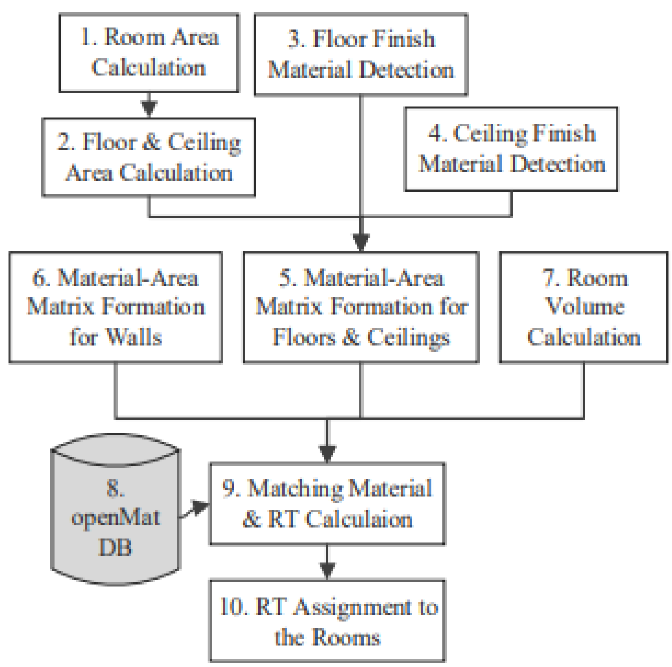

Figure 6 Process of RT calculation. (Lee & Nik-Bakht ,2019)

6.3.4 Occupants indoor environment quality preference test

Digital technology also can be applied to explore occupants’ preferences regarding indoor environment quality. Rosenlund, Li & Petersen, (2018) tested the correlation between occupants' thermal comfort and visual comfort applied VR and climate chambers. In the experiment, the climate room is used to simulate indoor scenes related to thermal comfort, while VR is used to stimulate visual perception. VR environments are built by using Sketch Up, then imported into the game development platform Unity. This experiment involved four different scenarios in which the temperature was kept at 25.5°C with small or big glazing, and the temperature was kept at 30.8°C with small or big-sized glazing in a VR environment. Finally, collect data on the thermal comfort of the occupants and their visual comfort through digital interactive questionnaires, the questions are related to two parts which about thermal comfort and view quality, the thermal comfort question surrounds the initial feeling of thermal comfort and adapted indoor thermal condition, and the view quality questions are related to visual comforts, such as the spacious rating and the comfort level on different positions. Rodrigue, Demers, & Parsaee (2020) proposed a method of tridimensional (3D) laser to scan existing buildings and, in conjunction with BIM, provide interior lighting information to light designers to help them better understand spatial lighting, and thus, improve occupant's visual comfort. A Trimble TX5 tridimensional laser scanner is used for 3D scanning and collecting point clouds, capturing data such as spatial geolocation and normal vectors of the surface, and creating BIM models based on the collected point clouds. Canon EOS 50D camera and the Photolux software make up the photo luminance meter system and generate HDR images with low to high Exposure Values (± 2ev). The resulting model can be used to observe the degree of illumination, and analyze the light distribution, light source, and light intensity changing with time. In addition, Chiou, Saputro & Sari (2020) evaluated the visual comfort of occupants based on HDR, a two-part study that involved questionnaires and field data collection. The questionnaire was designed to determine students' real feelings and visual comfort in class. The questions were about physical symptoms, visual disturbances and task performance, and user preferences. Field investigation is based on luminance mapping using HDR imaging techniques and the analysis of indoor luminance distribution. The data were collected using a Canon 7D camera, a Sigma Circular Fisheye lens 4.5 mm F2.8180 °, a Konica Minolta LS-110, and an illuminometer. There are two different settings in classrooms. One is to have all the lights on without a projector, and the other is to have the front lights on with the backlights off and a projector. In these classrooms, photographs are taken from full underexposure to full overexposure, and data on brightness, desktop illuminance, and vertical illuminance are collected for calibration purposes. The data collected is processed in photosphere software and Hdrscope, and glare analysis is performed using Evalglare. Finally, combining the results of the questionnaire, the paper analyzes the visual comfort of different positions in the classroom and the improvement scheme.

6.4 The contribution brought by digital technology to indoor environment quality

The application of digital technology can provide occupants with contributions, advantages, and conveniences and is summarized in the following:

1. Digital technology and users create an interactive information network that processes user data to improve the quality of life of residents.

2. VR applications allow users to interact with data in real-time and concisely, with simple intelligibility applicable to a wide range of people, real-time data updates, and displays.

3. Increase the productivity and efficiency of information sharing between acoustic professionals and architects.

4. If the indoor environment quality is poor, the system can operate and improve the indoor environment automatically in accordance with the pre-set occupant preferences or healthy indoor environment quality standards.

5. The application of the digital technology of automatic control of the appropriate equipment promotes comfort and reduces energy consumption and costs while maintaining a high level of occupant comfort.

6. The collected data of indoor thermal comfort can be used as the basis for the selection of indoor thermal insulation materials.

7. Digital technology devices applied to test indoor visual comfort allow the assessment and mapping of the percentage of available space for visual comfort, allowing investigation and visualization of lighting distribution patterns in different areas of space, in order to achieve the improvement of indoor lighting, to enhance the workers and students in the work and study of the sense of comfort and protection of vision.

8. Based on the data stored in the database, help users identify indoor environment quality problems and conduct further analysis.

9. Provide an alert to the resident's smartphone about the potential cause of discomfort for the resident to monitor remotely and take action as appropriate to protect vulnerable individuals.

10. Accurate monitoring and forecasting are integrated into the overall building management system to ensure that occupants optimize and eliminate risks before being exposed to poor indoor environment quality.

11. Intelligent learning from the behavior of occupants and from historical data and self-adjusting systems to best respond to different types of people.

12. It allows for better and easier communication between the physical system and the stakeholders to design and operate the building with awareness and efficiency while meeting the needs of the occupants and maintaining the level of comfort they require.

7.0 Discussion and conclusion

Based on the background knowledge of indoor environment quality and digital technology, this paper puts forward digital technology that can be applied to indoor environment quality, indoor environment quality factors that can be influenced by digital technology, how digital technology applies on the indoor environment quality, and its contribution and well-being to occupants, and this paper has launched the widespread discussion and the research in view of these four problems. Based on the research and analysis of 15 relevant eligible papers, this paper applies the data and experimental cases in the eligible papers and provides a deep conceptual framework for the application, influence, and implementation of various digital technologies and indoor environment quality factors.The digital technologies that are currently being utilized to affect indoor environment quality include BIM, AR, IoT, Smart Sensors, VR, Tridimensional laser scanning, and High Dynamic Range Imaging, but these technologies are usually integrated to achieve multiple performance outcomes. Thermal comfort, acoustic comfort, indoor air quality, and visual comfort are influenced by these digital technologies and are mainly divided into four types of applications. The most common applications of these technologies include active or passive control of indoor equipment and real-time monitoring from a remote location. In addition, BIM, Tridimensional laser scanning, and High dynamic range image can also be applied to occupant's preference test and Building performance evaluation. These technologies are being applied to provide occupants with simple, easy-to-understand real-time data detection, management, and control of indoor environment quality, and contribute to health and safety, as well as helping designers of various professions to analyze and optimize different indoor space designs more reasonably, which provides convenience for people.

Despite addressing the possibilities and contributions of digital technology in the field of indoor environment quality, the paper is still one-sided. This paper does not consider the negative influences when applying these digital technologies, such as environment quality control costs, energy consumption, and the lack of research on the impact of long-term use of digital technology. Furthermore, the types of indoor spaces that are involved in the 15 eligible papers are not the same, including ordinary houses, classrooms, office buildings, and so on. Due to the limited scope of the paper, it is impossible to prove that these digital technologies can be applied to all types of indoor spaces, the lack of research on one type of indoor space is a limitation.

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Appendix A

Assessing the quality of studies						
No.	Title	year	Author	Total	Question 1	Question2
1	A receptive-responsive tool for customizing occupant's thermal comfort and maximizing energy efficiency by blending BIM data with real-time information	2021	Birgonul, Z	6	3	3
2	Air pollution monitoring using augmented reality	2018	Aswin, P Adhiyaman Posonia, A.M.	4	2	2
3	BIM-based Simulation for Analysis of Reverberation Time	2019	Lee, J Nik-Bakht, M.	6	3	3
4	Development of an IoT-Based Indoor Air Quality Monitoring Platform	2020	J,Jo B, Jo J, Kim S, Kim W,Han	5	2	3
5	Energy savings of retrofitting residential buildings with variable air volume systems across different climates.	2020	Lu, D Warsinger, D	3	1	2
6	Hybrid Ventilation System and Soft-Sensors for Maintaining Indoor Air Quality and Thermal Comfort in Buildings	2020	Vadamalraj, N. Zingre, K. Seshadhri, S. Arjunan, P Srinivasan, S.	6	3	3
7	Internet of Things and Enhanced Living Environments: Measuring and Mapping Air Quality Using Cyber-physical Systems and Mobile Computing Technologies.	2020	Marques, G Miranda, N Kumar Bhoi, A Garcia-Zapirain, B Hamrioui, S. de la Torre D ez, I	5	3	2
8	Investigating Indoor Environmental Quality Using Virtual Reality In	2018	Rosenlund, M Li, Y Petersen, S.	4	2	2
9	Lighting in the third dimension: laser scanning as an architectural survey and representation method. Intelligent Buildings International	2020	Rodrigue, M. Demers, C. Parsaee, M	5	2	3
10	Live Data Visualization of IoT Sensors Using Augmented Reality (AR) and BIM	2019	Natephra, W. Motamedi, A.	4	2	2
11	Monitoring Indoor Air Quality by using IoT Technology	2018	Esquiagola, J. Manini, M. Aikawa, A Yoshioka, L. Zuffo, M.	5	3	2
12	Sensing Data Fusion for Enhanced Indoor Air Quality Monitoring	2020	Ha, Q. Metia, S Phung, M.	6	3	3
13	Critical review and research roadmap of office building energy management based on occupancy monitoring	2019	Salimi, S Hammad, A.	4	2	2
14	The monitoring system of indoor air quality based on internet of things	2020	Pangestu, A Yusro, M. Djatmiko, W. Jaenul, A.	4	2	2
15	Visual Comfort in Modern University Classrooms	2020	Chiou, Y. Saputro, S. Sari, D.	3	2	1