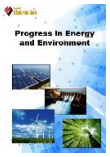
Progress in Energy and Environment

Journal homepage: http://www.akademiabaru.com/progee.html



Volume 13 (2020) 1-15

Original Article

Exploring the Application of Digital Data Management Approach for Facility Management in Shanghai's High-rise Buildings

OPEN ACCESS

Dan Wang[*,1], Khoo Terh Jing[2], Zhangfei Kan[3]

[1] School of Housing, Building and Planning, Universiti Sains Malaysia, Pulau Pinang
[2] School of Civil Engineering, Yangzhou Hospitality Institute, Yangzhou, China

Abstract

As property development and information technologies are going rapid in these few decades, information construction becomes necessarily as a management tool. It is vital to conduct research on facility management in high-rise buildings as many information technologies such as surveillance system and electrical appliances controlling are installed and applied in high-rise buildings. Intensive literature review was conducted and the required information from published journals articles was abstracted to identify digital data management approaches which have been used in high-rise building's facility management. A semi-structured interview which based on the information obtained from literature review was employed to collect data. Collected data is analyzed with the help of software Nvivo12 in the structure and function framework analysis which introduces the application effect of facility management system theory in the practical work and verify the function and value of eight key tools and software such as Computer Aided Facilities Management System, Radio Frequency Identification, Intelligent Building Management System, Intelligent Facilities Management System, Building Information Model, Wireless Sensor Technology, Mobile Intelligent Terminal and technical specification in facility management. Ultimately, a summary of the study which including eight key tools and software implementation that capable to reduce the cost of facility management in high-rise buildings are proposed which proves the necessity to promote digital data management in facility management of high-rise buildings.

Article Info

Received 10 April 2020
Received in revised form 8 May 2020
Accepted 12 May 2020
Available online 22 May 2020

Keywords

Digital data management
Facility management
High-rise buildings
Shanghai

1 Introduction

Facility management integrates multiple majors which can help facility management companies, construction units and government departments to manage daily maintenance operations while providing long-term planning to improve the economic efficiency of the company. The new generation of facility management system realizes the information integration of the building facilities from planning, design, procurement, installation and operation and maintenance throughout the life cycle which gives the facility managers with a database of information and knowledge integration that greatly improves the level of facility management. China's research on facility management is very less when compared to the foreign researches [1]. Therefore, China's facility management can refer to foreign mature facility management systems as there are many successful application cases that can be good

[*] **Corresponding author** dan.wang@student.usm.my ✉

references for the development in China facility management. However, due to differences in cultural and architectural environments between China and foreign countries, the facility management system that conforms to China's national conditions still needs further researches and practices to explore the most adequate application in this country.

Facility management can provide a high-quality environment on the basis of effective costs and save energy to improve energy utilization. At present, the world is facing serious energy shortages, such as resource depletion and environmental and climate deterioration. The issue of energy sustainability is currently the main global challenge. In major construction countries such as China, the development of the construction industry will promote the continuous consumption of energy. In order to ensure facility management can improve its efficiency and saving resource costs on the basis of providing performance, it is necessary to reduce growing energy consumption.

i. What are the available digital data and their importance during the operational phase of facility management in high-rise buildings?
ii. How digital data management approach lead to reduce the cost of facility management operation in high-rise buildings?

Therefore, conducting a research based on China's conditions is important as it can explore a facility management model that is in line with China's conditions and makes it practical.

The main objective of this study is to identify the most effective management approach of digital data and information for the operation of facility management in high-rise buildings in order to improve the financial performances. The study contributes to the existing knowledge in two ways: first, in terms of theoretical contribution, the findings will provide further understanding of different digital data management approaches used in high-rise buildings' facility management to reduce costs effectively; second, in terms of practical contribution, the findings will benefit the construction industry by giving references on the methods to use digital data and information management approaches in facility management which can improve the quality and reduce the cost of operation and facility management in high-rise buildings.

The structure of the remainder of this paper explores the literature review, which is focused on recent research outcomes that relevant to technology and facility management, an explanation on the research methodology applied, results, discussion and limitations, and finally a conclusion.

2 Literature Review

Facility management has many academic definitions. The International Organization for Standardization (ISO) defines facility management as the "organizational function which integrates people, place, process and technology within the built environment with the purpose of improving the quality of life of people and the productivity of the core business in conjunction with the auxiliary as well as the support services" [2]. Moreover, the European standard for facilities management defines it as "the integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities" [2].

In the initial stage of facility management development, it is only about the entity itself. For example, the facilities and equipment in construction project only focus within the project itself but not on the whole supply chain, thus, it is vital to conduct a research in order to make a more systematic study on this matter [2]. With the continuous research of scholars from various countries, the content of people and living environment have been added. This caused the contents of facility management becomes abundant. From the existing literature relevant to facility management, it is noticeable that the concept of the whole life cycle within facility management was ignored which further clarified the importance of the preliminary planning in facility management development [3].

As the concept of facility management is rising in popularity, every country has established their own facility management association where these associations will make country-specific definition based on the different developments of facility management in their own country [4]. This can be seen in the International Facilities Management Association that defines the facility management as "Facility management is put forward to keep the business space high quality of life and improve the efficiency

of the investment for the purpose, with the latest technology projecting, organizing the effective life of people and maintaining management. It combines the material workplace with the people and institutions, which composites business management, construction, the basic principles of behavioral science and engineering". According to the definition of the International Facilities Management Association, facility management mainly includes nine functions [5]:

i. long-term facility management plan (strategic and strategic plan)
ii. short-term facility management plan (daily execution plan)
iii. facility financing analysis and financial management
iv. real estate disposal and management
v. internal space planning
vi. space standards and space management
vii. construction planning and design of new or rebuilt projects
viii. construction of new or rebuilt projects
ix. daily operation and maintenance of facilities, communication, security and other support services.

In recent years, China's construction industry has developed rapidly. The rapid growth of buildings has brought a very large demand on facility management, especially the rapid emergence of modern high-tech buildings and high-paying technology houses, which are constantly improving the quality of owners and quality of life [6]. The mature facility management system and many successful application cases abroad have provided good references for the development of facility management in China [7]. Since 1992, International Facilities Management Association's branch has been established in Hong Kong. The facility management theory has gradually penetrated into the China's construction industry from Hong Kong and expanded its development in China's boundaries [8].

There are several topics related to facilities management and these topics covered under technology and facility management are:

i. Computer Aided Facilities Management (CAFM)

Computer Aided Facilities Management refers to the use of information technology that include the databases, Computer-aided design (CAD), geographic information systems (GIS) and computer networks to manage and support facility management tasks [9]. Facility management has been applied to a wide range of industries, such as government agencies, education, health care, commerce, and industry [10]. CAFM Systems can improve the performances of these industries by merging and analyzing data specific to each industry of facility management business [11]. A CAFM system can help facility managers to ensure all institutional facilities in high-rise building are fully utilized and help to maintain every phase of the building's life cycle where it can be operated with the lowest possible cost. The CAFM system is a digital management method that appeared earlier and used in facility management where It can determine the most effective digital data and information management approaches for high-rise buildings' operations and facility management which can reduce the operation and facility management costs effectively.

ii. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID), commonly known as electronic tag, is a non-contact automatic identification technology that automatically recognizes target objects and acquires relevant data through radio frequency signals [12]. The identification capability can identify moving objects and recognize multiple objects at the same time without manual intervention [13]. According to the characteristics of radio frequency identification technology, it has been applied to many industries such as supermarkets, logistics and railway transportation. As facilities management can be applied in various industry, information that needs to be collected and analyzed is very cumbersome. The large-scale application of radio frequency identification technology in the field of facility management can automate facility management, improve management efficiency, and

increase the speed of information flow. Specifically, RFID can be applied to several aspects of facility management [13]. For example, facility managers can store component information in the facility management system through RFID where damaged or non-functional components can be found on time. This can greatly prevent unexpected events which caused by the overlook of technicians. In addition, it can be effectively used in access control systems and equipment management such as tracking maintenance history, installing electronic tags at some pipeline switches or valves and the tags that include the date of last repairs. Moreover, the physical location of the equipment or system can be clearly detected through RFID which increase the work efficiency of the maintenance personnel. This can be achieved as information recorded in the RFID tag is synchronized to the facility management system. Through these measures mentioned above, maintenance personnel can intuitively know the operation status of the facility in the buildings [12].

iii. Wireless Sensor Technology

Wireless sensor technology is a comprehensive intelligent information technology that integrating information collection, information transmission and information processing. In the field of construction engineering and facility management, wireless sensor technology is often used to automatically collect a large amount of data information and transmit it to the system terminal for analysis through the wireless network, to help managers make judgments or to automatically control according to the conditions set [14]. For example, the building energy-saving control system, through the lighting, temperature, humidity and other sensors, to obtain various parameters of the environment inside the building. After the information is collected, the data will be sent to system terminal for analysis then the analyzed data will be send to the various energy-consuming equipment in the building (lighting, air conditioning Control and heater) to optimize the energy consumption of the entire building which can significantly reduce the energy consumption of high-rise buildings.

iv. Intelligent Building Management System (IBMS)

Intelligent Building Management System (IBMS) integrates into various equipment and related subsystems in the building where strict monitoring and management can be held on them. IBMS acts an integrated platform to improve the management efficiency within the entire building and reduce energy consumption and operating costs for the entire building [15]. The overall goal of the IBMS is to construct a spatial, energy, and logistics environment within the building through an integrated environment through the integrated integration technology, that is through the collection, monitoring and sharing of all information resources in the building and the information [15]. The organization, optimization and judgment provide the decision-making basis and the automation of execution control and management to the managers at all levels of the building [16].

v. Building Automation System (BA)

The Building Automation System (BA) is a subsystem of an integrated management system that requires the control and management of equipment within the building to provide the foundation for overall integration [17]. Integrated management system commands air conditioning, power distribution, water supply and drainage, parking garage, lighting, access control and patrol, audio and broadcast, burglar alarm and send exhaust fan. Information acquisition and control signals are integrated into the field controller in the network. The transmission path required for the upper control schedules various types of information of each subsystem collected by each field controller [18]. The energy consumption is relatively large in a typical building system such as the usage of air conditioning system to regulate the temperature of internal living environment to ensure comfortable environmental is provided to users. However, through BA, the energy consumption within intelligent BA system can be greatly saved. According to the Chauhan and Chauhan [17], the air conditioning system has highest energy consumption rate compared to other electric appliances which cause the operational cost turns higher. This can be solved by implementing central air conditioning system in

the building through the BA system where energy consumption can be reduced. Furthermore, controlling the electric appliances intelligently not only provide comfortable living environment but also lengthen enable electric appliances life span.

vi. Intelligent Facilities Management System (IFMS)

IFMS is an advanced comprehensive system involving the integration and information sharing of various subsystems [19]. It has the ability to communicate with the computer room environmental monitoring system, fire protection system, integrated security system, broadcasting system and anti-theft alarm system to realize the system [1]. The sharing of language, data, and image resources will separate the separated systems and devices into a whole. The function of IFMS is significant in handling emergency incidents such as fire accident in office based high-rise buildings.

vii. Mobile Intelligent Terminal

A mobile intelligent terminal is a terminal device capable of accessing the internet through one or more mobile network access modes, and the mobile intelligent terminal has the functions of storing and retrieving various information, real-time inputting, managing or processing necessary information, supporting text, sound and image. [20]. In the construction industry, mobile terminals combined with the internet and other technologies which gradually changed the way workers work [20]. The application value of mobile intelligent terminals in the construction industry is mainly reflected in the aspects of data acquisition, query function, mobile office and combined with other advanced technologies.

viii. Building Information Model (BIM)

BIM was first proposed in the late 1970s [21]. BIM gradually changed the traditional architectural model, which occurred in personnel management, process management, work culture, communication methods and business models [21]. BIM technology can provide framework management throughout the lifecycle of a building project and provide decision support and work processes at work [22]. Throughout the life cycle of the project, BIM can bring significant application value to all stakeholders of the project at all stages [23]. In the operation and maintenance phase, the BIM model can be used as a carrier for building delivery, and the BIM technology can be combined with the facility management information system to achieve true intelligent operation and maintenance [24].

3 Methodology

In this research study, secondary data are collected from relevant literature reviews from various sources to acquire more information and materials related to the study. These secondary data are then sorted to be used as interview questions in the interview sessions with respondents. Exploratory research survey method is then employed to answer research objectives which is to examine the current state of high-rise buildings in digital data and information management implementation and identify the effective management approach in digital data and information operation in high-rise buildings which can reduce the cost of operation and facility management. Furthermore, exploratory research survey method has the benefit of being flexible and easily adaptable to changes in the research environment and can be conducted with minimal cost in many cases [25].

In this research, primary data is collected by conducting research interview. A total of eleven respondents who are professional in facility management were interviewed to obtain insights on the potentials and implications of facility management in managing their implications in China. Among eleven respondents, three respondents have experience in facility management practices for more than ten years while eight respondents have experience in facility management implementation for more

than five years in high-rise buildings. Different perspectives were gained from the respondents as respondents were from different backgrounds and variety of organizations. Most of them are from property development companies who holding top management positions such as department managers and senior directors. All respondents are based in Shanghai where the projects they are focusing on are also in central business district of Shanghai. The interviews were carried out in participant's office on different days where the interview time is approximately forty minutes for each respondent. Respondents have provided relevant information and their opinions regarding on facility management which including the problems of managing high-rise buildings, solutions to solve those problems, type of tools and software to use and the correct way to apply digital data approaches to reduce operational costs. After interviewing these 11 respondents, the answers to the research questions have tended to be concentrated, which means that the results of the study have shown a trend of centralized performance, so there is no need to interview more respondents.

Furthermore, the collected interviews dialogs are read for multiple times in order to get familiar with the data. After collecting data from respondents, the collected data were summarized and organized by Nvivo 12, a professional software of data analysis which can analyses the data in the most effective and efficient way. It consists of summary of data, which highlights main trends and differences in the most appropriate manner.

4 Results

Eleven respondents who are professional with facility management were interviewed to obtain insights on the potentials and implications of facility management in managing implications of facility management in high-rise buildings. Different perspectives were gained from the respondents as respondents were from different backgrounds and variety of organizations. Table 1 shows the description of the respondents who participated in the interview.

Table 1 Respondent descriptions

Respondent ID	Description
R1	R1 is a senior director in a property development company. He has 10 years of experience in the construction industry and 10 years of experience practicing FM in the project. He used a case of Shanghai Vientiane City Project, which located in Minhang district Shanghai. He is an active practitioner of FM in the project.
R2	R2 is a department deputy manager in a property development company. He has 8 years of experience in the construction industry and 8 years of experience practicing FM in the project. He used a case of Shanghai Taikoo Dazhongli Project, which located in Jing'an district Shanghai. He is an active practitioner of FM in the project.
R3	R3 is an engineer in a contractor company. He has 5 years of experience in the construction industry and 5 years of experience practicing FM in the project. He used a case of Shanghai Langshi Green Center, which located in Changning district Shanghai.
R4	R4 is a department manager in a property development company. He has 12 years of experience in the construction industry and 10 years of experience practicing FM in the project. He used a case of Hesheng International Plaza Commercial Complex Project, which located in Yangpu district Shanghai. He is an active practitioner of FM in the project.
R5	R5 is a senior director in a property development company. He has 10 years of experience in the construction industry and 9 years of experience practicing FM in the project. He used a case of Shanghai Tianmu Road Yaojiang City Project, which located in Changning district Shanghai. He is an active practitioner of FM in the project.
R6	R6 is a senior director in a property development company. He has 11 years of experience in the construction industry and 8 years of experience practicing FM in the project. He used a case of Jinmao Shanghai North Bund Project, which located in Hongkou district Shanghai. He is an active practitioner of FM in the project.
R7	R7 is a department manager in a property development company. He has 13 years of experience in the construction industry and 11 years of experience practicing FM in the

	project. He used a case of CapitaLand Shanghai Longemont Square, which located in Changning district Shanghai. He is an active practitioner of FM in the project.
R8	R8 is a senior director in a property development company. He has 9 years of experience in the construction industry and 9 years of experience practicing FM in the project. He used a case of Shanghai Global Harbor, which located in Putuo district Shanghai. He is an active practitioner of FM in the project.
R9	R9 is an engineer in a property development company. He has 6 years of experience in the construction industry and 5 years of experience practicing FM in the project. He used a case of Shanghai Jinmao Building, which located in Jing'an district Shanghai.
R10	R10 is an engineer in a property development company. He has 5 years of experience in the construction industry and 5 years of experience practicing FM in the project. He used a case of Longhu Times Street, which located in Minhang district Shanghai.
R11	R11 is a commercial director in a property development company. He has 8 years of experience in the construction industry and 8 years of experience practicing FM in the project. He used a case of Changning Raffles Square, which located in Changning district Shanghai. He is an active practitioner of FM in the project.

Table 2 lists the answers to question of what are the tools/software/policy that used in managing facilities in high-rise buildings.

Table 1 Respondents' answers to question 1

ID	Respondents' answers to Q.1: *What are the tools/software/policy used in managing facilities of high-rise buildings?*
R1	*1. Computer Aided Facilities Management System (CAFMS);* *2. Intelligent Building Management System (IBMS);* *3. Intelligent Facilities Management System (IFMS);* *Technical specifications for relevant facilities and equipment developed by the state or industry.*
R2	*1. Computer Aided Facilities Management System (CAFMS);* *2. Radio Frequency Identification (RFID);* *3. Intelligent Building Management System (IBMS);* *Intelligent Facilities Management System (IFMS).*
R3	*1. Computer Aided Facilities Management System (CAFMS);* *2. Radio Frequency Identification (RFID);* *3. Wireless Sensor Technology (WST);* *Intelligent Building Management System (IBMS).*
R4	*1. Computer Aided Facilities Management System (CAFMS);* *2. Wireless Sensor Technology (WST);* *3. Intelligent Building Management System (IBMS);* *4. Building Information Model (BIM);* *Technical specifications for relevant facilities and equipment developed by the state or industry.*
R5	*1. Computer Aided Facilities Management System (CAFMS);* *2. Intelligent Building Management System (IBMS);* *3. Intelligent Facilities Management System (IFMS);* *Building Information Model (BIM).*
R6	*1. Computer Aided Facilities Management System (CAFMS);* *2. Radio Frequency Identification (RFID);* *3. Intelligent Building Management System (IBMS);* *4. Intelligent Facilities Management System (IFMS);* *Mobile Intelligent Terminal (MIT).*
R7	*1. Computer Aided Facilities Management System (CAFMS);* *2. Wireless Sensor Technology (WST);* *3. Intelligent Building Management System (IBMS);* *Building Information Model (BIM).*
R8	*1. Computer Aided Facilities Management System (CAFMS);* *2. Intelligent Building Management System (IBMS);* *3. Intelligent Facilities Management System (IFMS);* *4. Mobile Intelligent Terminal (MIT);*

	Building Information Model (BIM).
R9	*1. Computer Aided Facilities Management System (CAFMS);* *2. Wireless Sensor Technology (WST);* *3. Intelligent Building Management System (IBMS);* *4. Intelligent Facilities Management System (IFMS);* *Building Information Model (BIM).*
R10	*1. Computer Aided Facilities Management System (CAFMS);* *2. Mobile Intelligent Terminal (MIT);* *3. Intelligent Building Management System (IBMS);* *4. Intelligent Facilities Management System (IFMS);* *Building Information Model (BIM).*
R11	*1. Computer Aided Facilities Management System (CAFMS);* *2. Mobile Intelligent Terminal (MIT);* *3. Intelligent Building Management System (IBMS);* *4. Intelligent Facilities Management System (IFMS);* *Building Information Model (BIM).*

Figures 1 - 6 summarize the results of question 1 using the Nivivo 12 software model.

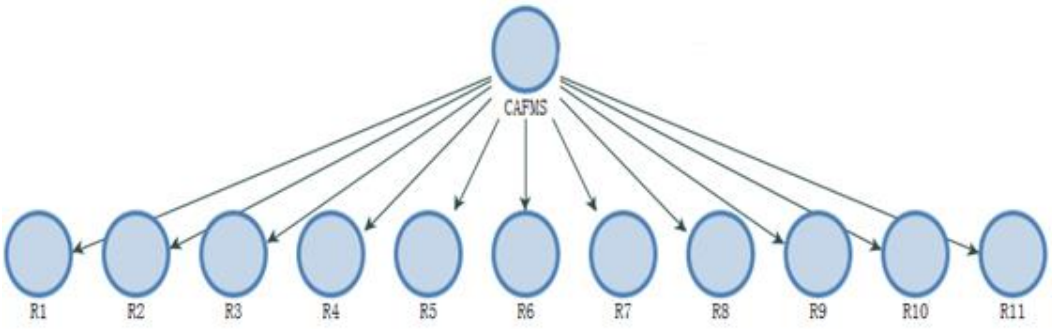


Fig. 1 CAFMS in facility management.

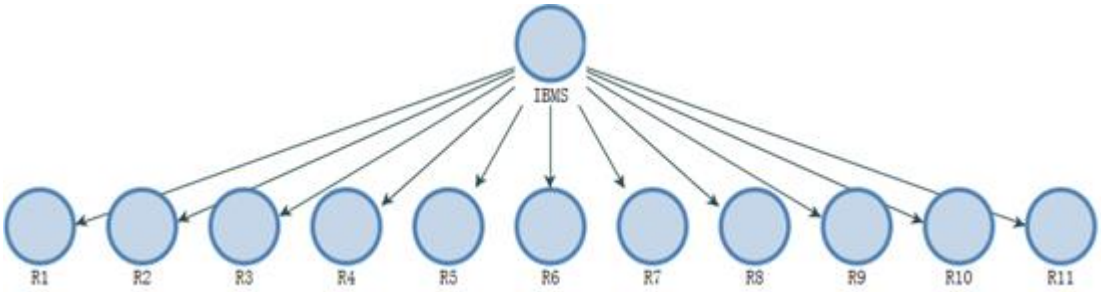


Fig. 2 IBMS in facility management.

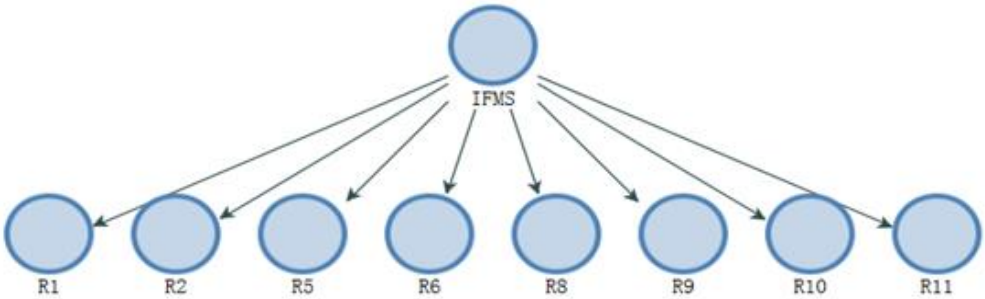


Fig. 3 IFMS in facility management

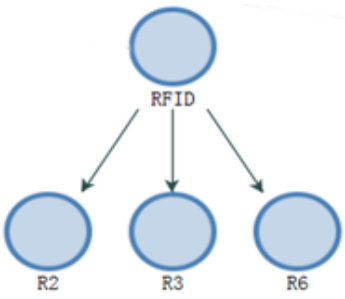


Fig. 4 RFID in FM.

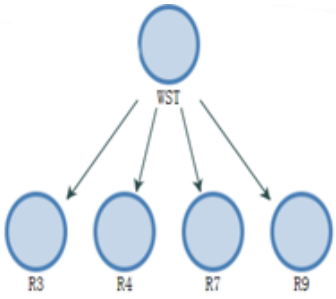


Fig. 5 WST in FM.

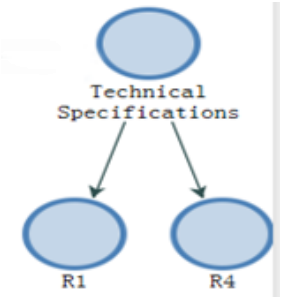


Fig. 6 Technical specification in FM.

Table 3 lists the result of key points of tools about facility management.

Table 3 Eight key points of tools about facility management.

Tools and Software Used in Facility Management	Proposed Frequency
1. Computer Aided Facilities Management System (CAFMS)	100%
2. Integrated Building Management System (IBMS)	100%
3. Intelligent Facilities Management System (IFMS)	73%
4. Building Information Model (BIM)	64%
5. Wireless Sensor Technology (WST)	36%
6. Mobile Intelligent Terminal (MIT)	36%
7. Radio Frequency Identification (RFID)	27%
8. Technical Specification	18%

Table 3 shows the results from the interview sessions held with respondents on the tools and software used in facility management. The results show that all respondents are familiar with the CAFMS and IBMS technology tool or software. This result is in line with Araszkiewicz [10]'s research who said CAFMS and IBMS are famous among practitioners which further strengthen the credibility and reliability of this research's results. IFMS and BIM gained most recognition where these two tools were fully applied by more than 50% of the respondents. Next, IFMS and BIM technology tools were highly applied in facility management too as the application of these two tools were 73% and 64% respectively. This result is supported by Araszkiewicz [10]'s research who proved IFMS and BIM are more popular among practitioners in facility management. WST and MIT are unpopular compared to the tools mentioned above. The percentages of WST and MIT technology tools applied in facility management are both 36%. The following is the application of RFID technology tool in facility management by interviewed respondents which only show 27% of usage rate among respondents. The result is same with Xue, Chen, Lu, Niu and Huang [12]'s research which stated the application of RFID technology in facility management is very rare.

Lastly, the application of technical specification is the lowest where only 18% recorded among respondents. From the interview sessions, CAFMS, IBMS and IFMS are the main tools which used by the industry in helping to manage facilities in high-rise buildings.

Table 4 lists the answers to question of the advantages of using digital data systems in facility management in high-rise buildings.

Table 4 Respondents' answers to question 2.

ID	Respondents' answers to Q.2: *What are the advantages of using digital data systems in facility management of high-rise buildings?*
R1	*Rational use of digital data to quickly and accurately understand the operation and usage of facilities and equipment.*
R2	*It allows users to clearly understand the dynamics of assets.*
R3	*1. Integrated delivery guarantees completeness, relevance and consistency of information;*

	2. The facility management personnel can plan the space model according to their own needs which based on the three-dimensional model of the building body. The users can make changes at any time and formulate a reasonable plan to maximize the use of space.
R4	*BIM provides a collaborative sharing platform for all stakeholders in the facility which enable information sharing and avoiding "information islands".*
R5	*Digital facility management has the advantages of convenience, speed and sharing.*
R6	*1. The integrated system platform ensures the completeness, relevance and consistency of information;* *2. Information sharing can avoid information islands.*
R7	*BIM provides a collaborative sharing platform for all stakeholders in the facility which enable information sharing and avoiding "information islands".*
R8	*1. Using the BIM model, facility managers can record the space utilization of buildings and help in analysing the planned building space;* *2. The BIM model covers all data, information and knowledge in the design and construction phases which ensuring the completeness, relevance and consistency of the information.*
R9	*Using the BIM model, facility managers can record the space utilization of buildings, help in analysing the planned building space, and have high management efficiency and technical skills.*
R10	*BIM provides a collaborative sharing platform for all stakeholders in the facility which enable information sharing and avoiding "information islands".*
R11	*1. Strong scientific management;* *2. Strong management purpose.*

Fig. 7 summarizes the result of question 2 using the Nivivo 12 software model.

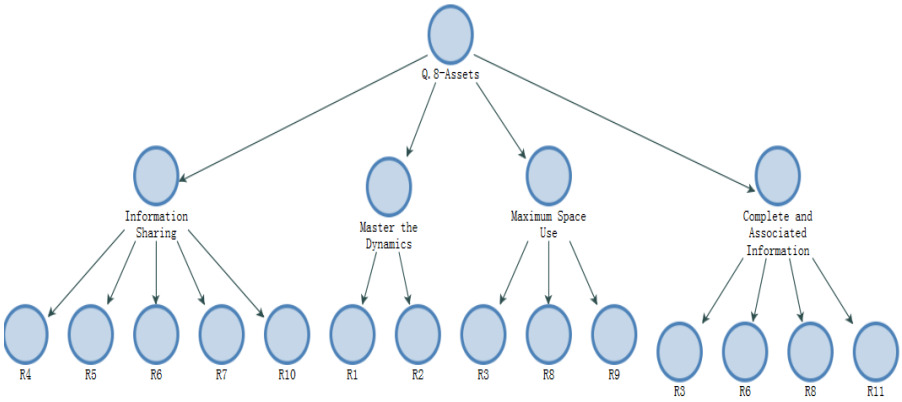


Fig. 7 Four key points of advantages in facility management.

Table 5 lists the result of key points of advantages using digital data technology in facility management.

Table 5 Four key points of advantages in facility management

Advantages	Proposed Frequency
1. Information Sharing	45%
2. Make Information Complete and Consistent	36%
3. Maximum Space Using	27%
4. Master the Dynamics of Assets	18%

Table 5 shows the outcomes from the interview sessions held with respondents on the advantages of using digital data technology in facility management. Information sharing is the most significant benefit by practicing facility management where nearly half of respondents (45%) believe the primary advantage of applying digital data management methods in facility management is to gain information sharing. In Hu, Zhang, Yu, Tian and Xiang [5]'s research, BIM-based facility management system is capable to share information which delivered from previous phases and these information can improve the efficiency during the operation and maintenance period. Next, according to 36% of the respondents,

applying digital data management can ensure the collected information from high-rise building is complete and consistent. Alfalah and Zayed [8]'s research about sustainable facility management systems revealed that the digital data management approaches can maintain the consistency in information collection. Through digital data management, available space can be maximized but only 27% of the respondents agree with this statement. Lastly, only 18% of the respondents said that practicing digital data management can master the dynamics of assets. From the outcomes, practicing digital data management have several strengths that gained consensus agreement from respondents which are information sharing and making information complete and consistent for managing facilities in high-rise buildings.

Table 6 lists the answers to the question of how to use digital data system to save costs in facility management in high-rise buildings.

Table 6 Respondents' answers to question 3.

ID	Respondents' answers to Q.3: *How to use digital data system to save costs in facility management of high-rise buildings?*
R1	*Training professional talents, using various office software, developing various management procedures, etc.*
R2	*Rationally plan the entry and exit of assets and reduce unnecessary expenditures.*
R3	*According to the data curve of the data system, timely make a reasonable analysis and corresponding adjustment to the operating cost where they have obtained the lowest cost to achieve the best management effect.*
R4	*1. Maximize investment by reducing the cost of building maintenance;* *2. Save money through effective space management.*
R5	*1. Save management costs through effective space management;* *2. Maximize the optimal life cycle cost by conducting a full life cycle economic analysis and evaluation of the facility.*
R6	*Maximize optimal life cycle costs by conducting a full life cycle economic evaluation of the facility.*
R7	*The digital facility management system can realize the closed-loop management of facilities and equipment, so that the facilities and equipment can maintain a good production state in the fierce market competition, maximize the performance, save costs and create profits for the enterprise.*
R8	*Through the dynamic data analysis and statistical analysis functions of the asset platform, it can generate useful data information for assets, complete complex and cumbersome data analysis tasks related to assets and reduce operating costs.*
R9	*Through the refinement of digital management, reduce project cost, strengthen asset economy operation management, reduce operation and maintenance costs, improve asset retirement supervision procedures, standardize treatment processes, strengthen technical appraisal, strengthen asset decommissioning and scrapping management, and realize the entire life of assets cycle management.*
R10	*Save money through effective space management in a digital facility management platform.*
R11	*1. The linkage between various formats is more direct and faster;* *2. Information exchange reduces costs faster.*

Fig. 8 summarizes the result of question 3 using the Nivivo 12 software model.

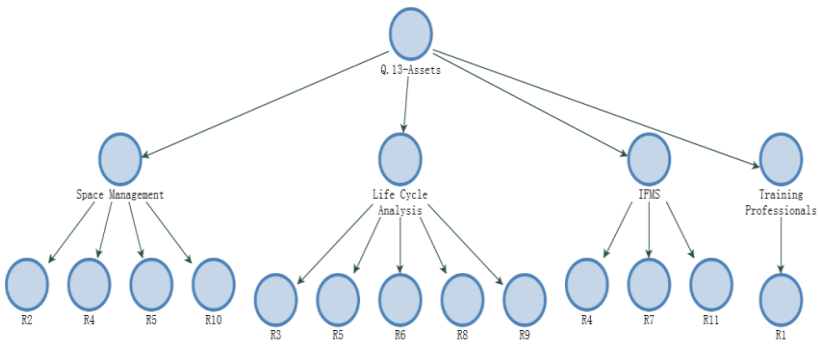


Fig. 8 Four key points of save costs in facility management.

Table 7 lists the result of key points of save costs in facility management.

Table 7 Four key points of save costs in facility management.

How to Save Costs	Proposed Frequency
1. Life Cycle Analysis	45%
2. Space Management	36%
3. Intelligent Facilities Management System (IFMS)	27%
4. Training Professionals	9%

Table 7 shows the outcomes from the interview session held with respondents on the methods to save costs by using digital data technology methods in facility management. 45% of the respondents believe the using of life cycle analysis is the primary approach to save costs in facility management. Respondent 3 said that *"According to the data curve in data system, reasonable analysis and corresponding adjustment can be made to the operating cost over time where the lowest cost can be achieved through the best management effect. The optimization of life cycle cost can be achieved by conducting a full life cycle economic analysis and evaluation on the facility through the dynamic data analysis and statistical analysis functions of the asset platform. This can generate useful data information for assets which are complex and cumbersome which related to assets and operating costs."* Respondent 5, 6, 8 and 9 agreed that life cycle analysis will reduce operating costs through the application of dynamic data analysis and statistical analysis functions of the asset platform.

According to Potkany, Vetrakova and Babiakova [3]'s research in 'Facility Management and Its Importance in the Analysis of Building Life Cycle', there is explanation on the application of life cycle costs which stated *"building life cycle costs represent the total costs from all life cycle phases, which according to given analysis have to be calculated as present net value. most of operational costs are conditioned by space and material solutions and its technical equipment… accepting suggestions of a facility manager and their implementation into project design can influence the effective services management of facility management in the phase of building use and consequently also to the life time of a building."* Next, 36% of the respondents said the utilizing of space management can greatly save the cost. Respondent 2 said that *"From the application of space management, it can save management costs through effective space management in a digital facility management platform."* Respondent 4, 5 and 10 mentioned the same thing regarding the usage of space management in facility management. They mentioned that space management can save management costs effectively.

However, the application of IFMS is less popular among respondents as only 27% of the respondents practice it in facility management. Respondent 7 said that *"The digital facility management system can realize the closed-loop management of facilities and equipment, so that the facilities and equipment can maintain a good production state in the fierce market competition, maximize the performance, save costs and create profits for the enterprise."* Respondent 4 and 11 both mentioned this point of using IFMS in facility management. They mentioned that IFMS can realize the closed-loop management of facilities so that the facilities can maintain a good production state in the fierce market competition then save costs and create profits for the enterprise. Lastly, only 9% of the respondents train their staffs to be professionals in facility management in order to save operational costs. Respondent 1 said *"The training of professional talents to use various office software and developing various management procedures might be risky as these workers might quit after they have gain sufficient experiences"* From the outcomes, life cycle analysis and maximizing space management are both are important tools and software of digital data management approaches that have been used to save costs in managing facilities in high-rise buildings.

5 Discussions

From the secondary data collection through literature review, the most effective management approaches of digital data and information management tools and software such as Computer Aided Facilities Management System [11], Radio Frequency Identification [12], Intelligent Building

Management System [15], Building Automation System[17], Intelligent Facilities Management System [19], Building Information Model [22], Wireless Sensor Technology [14] and Mobile Intelligent Terminal [20] have been explored. They can improve management efficiency of facility managers [24], increase the speed of information flow, help practitioners to make judgments [8], reduce staffs' workload and reduce operation costs [15]. For example, the implementation of digital data systems in managing assets can help to understand the dynamics of assets clearly and the operation of facilities [26]. Practicing BIM in assets management help to record the space utilization of buildings [3], analyze the planned building space and eventually improve management efficiency [26] and technical skills of practitioners which can ensure the information to be complete, relevant and consist among stakeholders [26].

The main objective of this study is to identify the most effective management approach of digital data and information for the operation of facility management in high-rise buildings in order to improve the financial performances. The structure of the interview questions is gradually into depth which started from what the tools and advantages of these tools and end with the approaches to save the costs. This sequence of interviews arrangement can make the survey results more relevant and coordinated. The research findings reveal the effective management approaches of digital data and information management in high-rise buildings is related to the application of digital data systems and software such as Computer Aided Facilities Management System [11], Radio Frequency Identification [12], Intelligent Building Management System [15], Building Automation System[17], Intelligent Facilities Management System [19], Building Information Model [22], Wireless Sensor Technology [14] and Mobile Intelligent Terminal [20]. These software and tools can help facility managers to manage facilities effectively. Such as implementation of space management, life cycle analysis, training professionals and system integration platform management can achieve the objectives of improving efficiency, reducing workload, improving accuracy and reducing costs in the phase of operation and facility management.

Respondent 1 and 2 mentioned that *"the adoption of digital data systems in managing assets can clearly understand the dynamics of assets and the rational use of digital data to quickly and accurately understand the operation and usage of facilities"* Respondents 1 and 2 strongly suggest the adoption of data system in high-rise building management as the implementation will greatly reduce the operational costs. Moreover, respondent 4, 5, 6, 7 and 10 said *"BIM provides a collaborative sharing platform for all stakeholders in the facility which enable information sharing and avoiding information islands."* Information sharing is the most significant benefit and this result is consistent with Hu, Zhang, Yu, Tian and Xiang [5]'s research results where a BIM-based facility management system can share information delivered from previous phases and improve the efficiency which further clarify the accuracy of this research findings. BIM model covers all data, information and knowledge in the design of every construction phases which ensure the completeness, relevance and consistency of the information that can be access by staffs [21]. In addition, the facility management personnel can plan the space model according to their own needs where three-dimensional model of the building body can be amended at any time, thus, formulate a reasonable plan to maximize the use of space. Furthermore, through the implementation of BIM model, facility managers can record the space utilization of buildings which can help to analyze the planned building space [24]. This will allow facility manager to have high management efficiency and technical skills.

6 Conclusion

This study aimed to explore the method to achieve digital data and information effective management during the operation phase of facility management. Nvivo 12 software is used for data management to accelerate the achievement of the research objectives. This software is simple in operation, but it has a systematic classification of data management, which makes data analysis easier to be comprehend and it greatly improves the efficiency of data management. Exploratory research survey method which is one of qualitative methods was employed to achieve research objectives where eight key tools and software were identified to be implemented in facility management of high-rise buildings. These tools and software are Computer Aided Facilities Management System, Radio

Frequency Identification, Intelligent Building Management System, Intelligent Facilities Management System, Building Information Model, Wireless Sensor Technology, Mobile Intelligent Terminal and technical specification. These software and tools have been proved to bring several advantages such as information sharing, making information complete and consistent, maximum space using and mastering dynamics of assets which can help facility managers to manage facilities effectively. The implementation of space management, life cycle analysis, training professionals and system integration platform management will greatly reduce the operational costs.

This research findings gave insights to the implementation of facility management in high-rise buildings by providing references on the usage of digital data and information management approaches in facility management which can improve the quality of management. Implementation of digital data and information management will reduce the cost of operation and facility management in high-rise buildings. Various digital data management approaches are applied in high-rise buildings to reduce costs effectively. Future researches are recommended to study in-depth from the perspective of BIM in the phase of operation and facility management. Moreover, future researches can focus on other digital data management approaches that can be compared with the performances of BIM adoption.

7 Research Limitation

First, respondents were interviewed in their office hours which cause the interview time to be constrained. Respondents might not have sufficient time to express their opinions. Next, the immature BIM implementation in China cause this practice to be not fully utilized in high-rise buildings. Therefore, most of the strengths in BIM implementation stated in existing literature were found missing in China. However, BIM acts as assisting tool in China's facility management which is used in the operation and facility management in high-rise buildings.

References

[1] Y. Cao, X. Song, T. Wang, Development of an Energy-Aware Intelligent Facility Management System for Campus Facilities, Procedia Engineering 118 (2015) 449-456.
[2] J. Xu, W. Lu, F. Xue, K. Chen, 'Cognitive facility management': Definition, system architecture, and example scenario, Automation in Construction 107 (2019) 102922.
[3] M. Potkany, M. Vetrakova, M. Babiakova, Facility Management and Its Importance in the Analysis of Building Life Cycle, Procedia Economics and Finance 26 (2015) 202-208.
[4] P. Pittet, C. Cruz, C. Nicolle, An ontology change management approach for facility management, Computers in Industry 65 (2014) 1301-1315.
[5] Z.-Z. Hu, J.-P. Zhang, F.-Q. Yu, P.-L. Tian, X.-S. Xiang, Construction and facility management of large MEP projects using a multi-Scale building information model, Advances in Engineering Software 100 (2016) 215-230.
[6] J. Yuan, L. Li, E. Wang, M.J. Skibniewski, Examining sustainability indicators of space management in elderly Facilities—a case study in China, Journal of Cleaner Production 208 (2019) 144-159.
[7] X. Liu, J. Zhou, Y. Xue, S. Qian, Analysis of property management ecological behavior in China based on the grounded theory: The influencing factors and the behavior model, Journal of Cleaner Production 235 (2019) 44-56.
[8] G. Alfalah, T. Zayed, A review of sustainable facility management research, Sustainable Cities and Society 55 (2020) 102073.
[9] J.K.W. Wong, J. Ge, S.X. He, Digitisation in facilities management: A literature review and future research directions, Automation in Construction 92 (2018) 312-326.
[10] K. Araszkiewicz, Digital Technologies in Facility Management – The state of Practice and Research Challenges, Procedia Engineering 196 (2017) 1034-1042.
[11] L. Róka-Madarász, L. Mályusz, P. Tuczai, Benchmarking facilities operation and maintenance management using CAFM database: Data analysis and new results, Journal of Building Engineering 6 (2016) 184-195.
[12] F. Xue, K. Chen, W. Lu, Y. Niu, G.Q. Huang, Linking radio-frequency identification to Building Information Modeling: Status quo, development trajectory and guidelines for practitioners, Automation in Construction 93 (2018) 241-251.

[13] W. Lu, G.Q. Huang, H. Li, Scenarios for applying RFID technology in construction project management, Automation in Construction 20 (2011) 101-106.
[14] M. Frei, C. Deb, R. Stadler, Z. Nagy, A. Schlueter, Wireless sensor network for estimating building performance, Automation in Construction 111 (2020) 103043.
[15] Z. Chen, F. Wang, Q. Feng, Cost-benefit evaluation for building intelligent systems with special consideration on intangible benefits and energy consumption, Energy and Buildings 128 (2016) 484-490.
[16] A. GhaffarianHoseini, T. Zhang, O. Nwadigo, A. GhaffarianHoseini, N. Naismith, J. Tookey, K. Raahemifar, Application of nD BIM Integrated Knowledge-based Building Management System (BIM-IKBMS) for inspecting post-construction energy efficiency, Renewable and Sustainable Energy Reviews 72 (2017) 935-949.
[17] R.K. Chauhan, K. Chauhan, Building automation system for grid-connected home to optimize energy consumption and electricity bill, Journal of Building Engineering 21 (2019) 409-420.
[18] Q. Gu, H. Ren, W. Gao, J. Ren, Integrated assessment of combined cooling heating and power systems under different design and management options for residential buildings in Shanghai, Energy and Buildings 51 (2012) 143-152.
[19] J. Lee, Y. Jeong, Y.-S. Oh, J.-C. Lee, N. Ahn, J. Lee, S.-H. Yoon, An integrated approach to intelligent urban facilities management for real-time emergency response, Automation in Construction 30 (2013) 256-264.
[20] X. Lu, Z. Pan, H. Xian, An integrity verification scheme of cloud storage for internet-of-things mobile terminal devices, Computers & Security (2019) 101686.
[21] J. Li, K. Afsari, N. Li, J. Peng, Z. Wu, H. Cui, A review for presenting building information modeling education and research in China, Journal of Cleaner Production 259 (2020) 120885.
[22] Z. Ding, J. Niu, S. Liu, H. Wu, J. Zuo, An approach integrating geographic information system and building information modelling to assess the building health of commercial buildings, Journal of Cleaner Production 257 (2020) 120532.
[23] B. Grzyl, E. Miszewska-Urbańska, M. Apollo, Building Information Modelling as an Opportunity and Risk for Stakeholders Involved in Construction Investment Process, Procedia Engineering 196 (2017) 1026-1033.
[24] N.D. Aziz, A.H. Nawawi, N.R.M. Ariff, Building Information Modelling (BIM) in Facilities Management: Opportunities to be Considered by Facility Managers, Procedia - Social and Behavioral Sciences 234 (2016) 353-362.
[25] D.S. Nielsen, Overview of qualitative research methods, Bone 48 (2011) S51.
[26] J. Heaton, A.K. Parlikad, J. Schooling, A Building Information Modelling approach to the alignment of organisational objectives to Asset Information Requirements, Automation in Construction 104 (2019) 14-26.