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Application of BIM5D Technology in the Construction of Super High-Rise Buildings

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Abstract: Super high-rise buildings are iconic landscapes of modern cities, but they face technical challenges in design, construction, and use. Building Information Modeling 5 Dimensions (BIM5D) technology, as an integrated data management platform, provides new solutions for the construction of super high-rise buildings by combining three-dimensional geometric models, time, and cost dimensions. This article first introduces the BIM5D technology framework, including its quantitative analysis methods in construction cost, time, and risk management. Subsequently, it explored the construction and integration process of the BIM5D model, as well as the application of construction simulation and visualization technology in project management. The experimental results show that BIM5D technology significantly improves construction efficiency, with a minimum project productivity of 62 square meters per day. In terms of quality control, the construction qualification rate is as high as 98.9%, reducing errors and rework during the construction process. In terms of cost savings, the highest savings reached 4.53 million USD, demonstrating the potential of BIM5D technology in cost management. Compared with traditional construction methods, BIM5D technology has shown significant advantages in multiple key performance indicators, including shortened construction cycles, improved labor productivity, and reduced material waste.

1. Introduction

Super high-rise buildings, with their unique aesthetic features and functional requirements, have gradually become an important component of modern urban skylines. However, these types of buildings face numerous technical challenges in the design and construction process, including structural safety, construction efficiency, cost control, and so on. Traditional 2D and 3D technologies have shown limitations in addressing these challenges, and there is an urgent need for a more advanced and integrated solution.

This article studies the application of BIM5D technology in the construction of super high-rise buildings, aiming to explore its potential in optimizing construction processes, improving construction efficiency, reducing costs, and ensuring construction safety. Through a comprehensive review of existing literature, this article not only summarizes the theoretical foundation and practical application of BIM5D technology, but also demonstrates the specific effects and advantages of BIM5D technology in construction management through practical case analysis. In addition, this article also analyzes the limitations of BIM5D technology and proposes corresponding improvement suggestions.

This article is divided into five parts. The first part is the introduction, which introduces the background, technical challenges, and basic concepts of BIM5D technology in the construction of super high-rise buildings. The second part is related work, summarizing the research achievements of the world in the field of super high-rise building construction, providing a theoretical and practical basis for the research in this article. The third part elaborates on the BIM5D technology framework, model construction and integration methods, as well as construction simulation and visualization technology. The fourth part demonstrates the application effect of BIM5D technology in actual construction projects and compares it with traditional construction methods. Finally, the fifth part is the conclusion, summarizing the advantages and limitations of BIM5D technology, and proposing prospects for future research directions.

2. Related Work

In today's world, with the acceleration of urbanization, super high-rise buildings have become a landmark landscape of modern cities due to their unique aesthetics and functions. However, these types of buildings face many technical challenges in the design, construction, and use processes. Tian Wei elaborated on the concept of vertical deformation difference in super high-rise buildings and conducted theoretical derivation of vertical deformation during the construction process of super high-rise buildings. Afterwards, the finite element analysis method for vertical deformation during the construction process of super high-rise structures can be introduced. On this basis, the measures for controlling the vertical deformation difference of super high-rise buildings are classified, and the vertical deformation control of typical construction processes is analyzed, proposing economically reasonable control methods [1]. Ren Hao took the construction site of the Zhaoping Business Center project as an example to study the occurrence of fires in super high-rise construction and the corresponding personnel evacuation issues. He used neural networks to predict the ignition materials of a fire, and used fire dynamics simulation tools to simulate the fire, obtaining simulation data of fire smoke and temperature. On this basis, he considered the impact of panic and construction environment, and conducted evacuation research on construction site personnel using Pathfinder [2]. Based on the actual engineering situation, Xu Ping has carried out automated monitoring of the entire construction process from the perspective of ensuring engineering quality and structural safety, in response to the construction difficulties caused by height exceeding, irregular shape, stress and complex construction of super high-rise buildings [3]. Ma Zhipeng was based on the complex and variable external contours of super high-rise building structures, poor sealing and overall integrity of the construction scaffolding system at corners, and poor adaptability to buildings with different structural shapes. On the basis of the original climbing frame, a push-pull sliding protective shielding frame has been developed and designed, which is to install sliding modules on the original frame and achieve corner closure of the frame through module sliding, meeting the requirements of irregular building structures [4]. Xiang Miao analyzed the local seismic effect of deep foundation pit support and pressure bearing structures in the construction of super high-rise buildings under earthquake action, and applied finite element software to analyze a certain super high-rise deep foundation pit project. He established a finite element calculation model for the deep foundation pit support and pressure bearing structure in super high-rise construction, and used a seismic simulation vibration table to input surface motion accelerations of 0.4g, 0.5g, and 0.6g during earthquakes. He compared the seismic performance of deep foundation pit support pressure structures with different construction stages and insertion ratios of underground continuous walls [5].

In addition, Szołomicki J conducted a survey on selected slender high-rise buildings, considering the structural improvements of high-rise buildings in the past decade from the perspective of architecture and structure [6]. Wu X applied seismic interferometry to the environmental noise recorded by dense seismic arrays, demonstrating the effective application of seismic environmental noise interferometry in structural health monitoring and global hazard assessment of super tall buildings [7]. Ilgın H E collected data from 27 buildings using literature review and case study methods to analyze the spatial efficiency of contemporary super high-rise residential buildings [8]. Kalantari S conducted a comprehensive and systematic evaluation of research on high-rise buildings after occupancy to assess the current state of knowledge, determine whether temporary conclusions can be drawn from existing research, and identify important areas for future investigations [9]. Bazhenov Y has developed the optimal formula for concrete based on the calculation and experimental design of filling adhesives used in seismic high-rise integrated structures. He adopted destructive testing methods as the most accurate method for analyzing the physical, mechanical, and deformation properties of concrete [10]. After a comprehensive review of the research in the field of super tall buildings mentioned above, it is not difficult to find that although these studies have made significant progress in both theoretical and practical aspects, traditional two-dimensional and three-dimensional technologies are no longer able to meet the complexity and dynamic requirements of super tall building construction in terms of construction management. Therefore, this article focuses on the application research of BIM5D technology in the construction of super high-rise buildings, exploring how BIM5D technology can optimize construction processes, improve construction efficiency, reduce costs, ensure construction safety, and achieve sustainable development goals.

3. Method

3.1 BIM5D Technical Framework

BIM5D technology is an advanced application of building information modeling, which further integrates time and cost dimensions on the basis of three-dimensional geometric models, forming a multi-dimensional and integrated data management platform [11-12]. It displays the geometric and physical properties of buildings through precise 3D models, while combining construction progress and cost information with the model to achieve comprehensive simulation and management of the construction process.

In the application of BIM5D technology, the use of mathematical formulas can enhance quantitative analysis and optimization of the construction process. For example, through the integration of cost dimensions, BIM5D can accurately calculate and control construction costs. Assuming that the construction cost of a super high-rise building consists of material cost C_m, labor cost C_l, and equipment cost C_e, the total cost C_t is:

$$C_t = C_m + C_l + C_e \tag{1}$$

In addition, BIM5D technology can optimize construction progress using the time dimension. Through 4D simulation, the duration T of a specific construction task can be calculated, which helps project managers to arrange labor and resources reasonably and avoid project delays. If a construction task consists of multiple sub tasks with a duration of T_i for each sub task, then the total duration of the entire task is:

$$T = \sum_{i=1}^{n} T_i \tag{2}$$

i is the subtask index, and n is the total number of subtasks.

In terms of risk management, BIM5D technology can combine probability theory and statistical methods to quantitatively evaluate potential risks that may arise during the construction process. Assuming the probability of a risk event occurring is $P(R)$ and its potential cost impact is C_{impact}, the expected cost $E[C_{risk}]$ of the risk is:

$$E[C_{risk}] = P(R) \times C_{impact} \tag{3}$$

BIM5D technology not only provides quantitative analysis of construction costs, time, and risks, but also provides decision support for project teams to develop more scientific and accurate management strategies. This data and model-based approach makes the application of BIM5D technology in the construction of super high-rise buildings more efficient and accurate, ensuring the smooth progress of the construction process and the achievement of project goals.

3.2 Construction and Integration of BIM5D Model

In the construction of super high-rise buildings, building and integrating BIM5D models starts from the design phase, transforming design intentions into a multi-dimensional and integrated data platform [13-14]. At the design stage, BIM software is used to create the 3D geometric model of the building, which not only includes the shape and spatial layout of the building, but also covers the details of the structural system and architectural elements. Subsequently, in the structural design phase, engineers carry out detailed design of structural elements such as beams, columns, and slabs of the building to ensure that they meet mechanical and safety requirements.

Table 1: Field Measurement Data

No.	Measurement Item	Point ID	Measured Value	Unit	Data Source	Remarks
1	Ground Elevation	SP01	35.6	m	Total Station	Bench Mark Calibration
2	Pit Depth	KP05	-12.4	m	Depth Gauge	Relative to Datum
3	Wall Plumbness	QW12	0.002	m	Laser Level	Deviation Value
4	Rebar Diameter	GJ08	25.4	mm	Caliper	Meets Design Specs
5	Concrete Strength	NT21	35	MPa	Pressure Tester	Compressive Strength
6	Soil Bearing Capacity	CD15	280	kN/m^2	Soil Test	Foundation Design Basis
7	Horizontal Displacement	YD09	0.5	mm	Displacement Monitor	Structural Stability

The MEP (Mechanical, Electrical, and Plumbing) design phase involves designing electrical, plumbing, and HVAC systems. BIM software simulates the layout of these systems to ensure their compatibility with building structures and interior design. As the design progresses, including precise modeling of building elements such as walls, floors, windows, and doors, the accuracy and details of this stage directly affect the accuracy and efficiency of construction.

In terms of multidisciplinary collaboration, the BIM5D model provides a shared platform that enables designers from different specialties to work on the same model, achieving real-time updates and feedback of design information, thereby ensuring consistency and accuracy of design information. Data integration imports data from CAD (Computer Aided Design) drawings, GIS (Geographic Information System) data, on-site measurement data, and other professional software. BIM software needs to have strong data compatibility and conversion capabilities in this process. As shown in Table 1, the on-site measurement data are as follows.

Table 1 provides a structured on-site data integration framework for the BIM5D model, helping to integrate on-site measurement data with other key project information such as design intent, construction plans, and cost control. This can form a comprehensive and dynamic project management view, thereby improving the transparency and predictability of the construction process, optimizing resource allocation, and reducing risks.

3.3 Construction Simulation

In the application research of super high-rise building construction, the construction process can be dynamically simulated through BIM5D technology. This not only helps to improve the understanding of the construction plan by the work team, reduce the risk of construction errors, but also greatly improves the efficiency and quality of construction disclosure, ensuring construction safety [15]. BIM5D technology integrates schedule and budget files into traditional BIM3D models, giving 3D models multiple attributes of time and cost. This integration allows for dynamic simulation of the construction process and enables timely monitoring of project progress and cost changes.

Through the BIM5D platform, it is possible to achieve refined production management, solve the problems of schedule management and multi-party collaborative work, and conduct three-dimensional complex node and process disclosure through a digital platform. In addition, the application of BIM5D technology in construction simulation also includes simulation of construction equipment, improvement of construction equipment, etc., to improve construction efficiency and quality.

By linking 3D models with on-site progress, BIM5D technology clarifies the location, time, and other information of various tasks, reduces workface conflicts, and provides early warning for key and difficult areas. Resource allocation is done well to ensure organized on-site management and the rationality of construction organization planning.

4. Results and Discussion

4.1 Actual Effects of BIM5D Technology Application

When exploring the application effect of BIM5D technology in the construction of super high-rise buildings, this article analyzes its specific performance in construction efficiency, quality control, and cost savings. As shown in Figure 1, the productivity under BIM5D technology is:

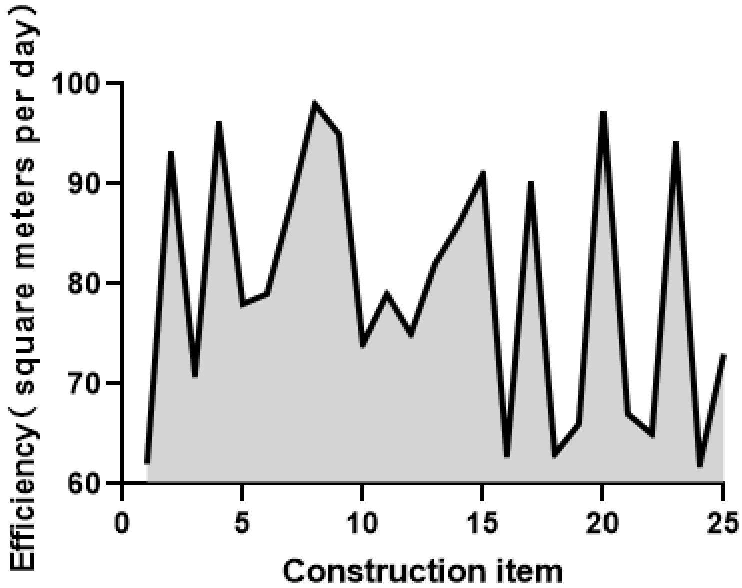

Figure 1: Productivity

As shown in Figure 1, the construction productivity of the project is as low as 62 square meters per day under BIM5D technology among these 25 construction projects. This indicates that even the most efficient projects have achieved a relatively high production level, highlighting the effectiveness of BIM5D technology in improving construction efficiency.

As shown in Figure 2, it shows the quality control of construction projects:

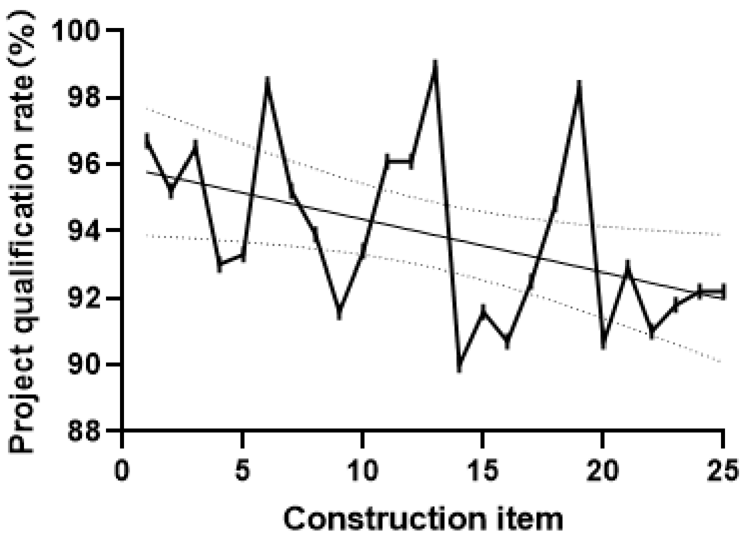

Figure 2: Qualification rate

Figure 2 shows the effect of BIM5D technology on project quality in the project. Under BIM5D technology, the highest construction qualification rate of the project reached 98.9%, and they are all at a very high level. This indicates that through BIM5D technology, construction teams can identify potential design issues and construction conflicts through precise 3D models during the design phase, thereby making necessary adjustments and optimizations before construction begins. This preventive quality control strategy greatly reduces errors and rework during the construction process, and improves the one-time success rate of construction.

Figure 3 shows the project cost savings data:

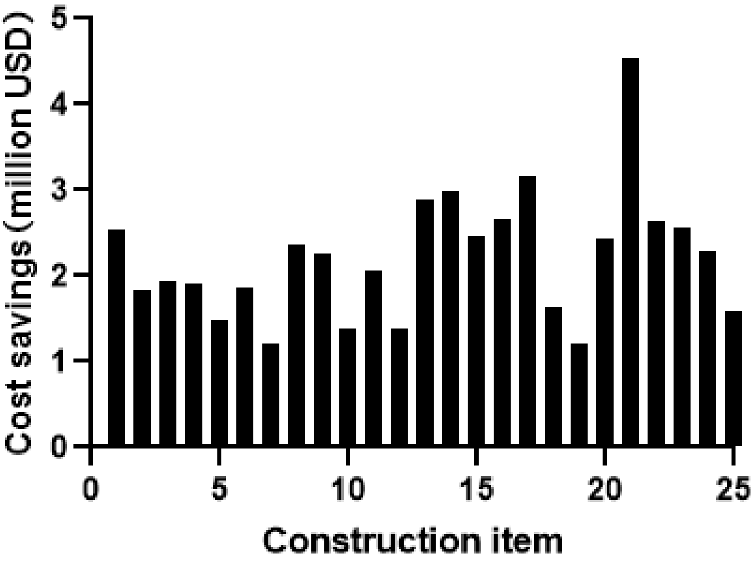

Figure 3: Cost savings

Figure 3 clearly indicates that construction projects under BIM5D technology have reduced construction costs, with the highest project savings reaching 4.53 million USD. This savings not only reflect the enormous potential of BIM5D technology in cost management, but also demonstrate the economic benefits achieved through refined management. Overall, the application of BIM5D technology in construction projects not only improves the accuracy and efficiency of project management, but also brings tangible economic benefits to project owners and contractors. With the further development and application of technology, it is expected that greater breakthroughs can be made in construction cost control in the future.

4.2 Improvement Points Compared to Traditional Construction Methods

The application of BIM5D technology in the construction of super high-rise buildings demonstrates its revolutionary advantages in project management compared to traditional construction methods. Compared with the traditional method, the application of BIM5D technology significantly improves the construction efficiency. In traditional construction practice, information transmission and communication are mostly based on two-dimensional drawings and scattered data, which is inefficient and often leads to data errors, and communication is invalid. In the construction site, BIM5D technology makes the information transmission more intuitive and effective, thus reducing the construction delay and rework caused by misunderstanding and information disconnection. In addition, the application of BIM5D technology in quality control, through the use of simulation and planned checkpoints, shifts the post-inspection of quality control to pre-prevention, and improves the construction quality. The influence of BIM5D technology on cost management enables the project team to monitor the cost expenditure in real time and effectively find, correct and manage the cost deviation. This is very difficult in traditional construction, because cost control is usually audited and corrected afterwards, while BIM5D technology transforms cost control into real-time and forward-looking projects. As shown in Table 2, the performance optimization data of BIM5D technology compared to traditional technologies are as follows:

Table 2: Project Performance Optimization Data

Construction Project Type	Construction Period Reduction (%)	Labor Productivity Increase (%)	Material Waste Reduction (%)	Cost Saving (%)	Safety Accident Reduction (%)	Design Change Reduction (%)	Construction Conflict Reduction (%)	Project Profit Margin Increase (%)
Urban Skyscrapers	10-25	20-40	15-30	10-20	40-60	20-35	30-50	15-25
Offshore Bridge	5-15	15-30	10-25	5-15	30-50	15-30	20-40	10-20
Commercial Plaza Development	8-20	25-35	12-28	8-18	45-55	25-40	35-45	12-22
Industrial Manufacturing Facilities	3-10	10-20	5-15	3-8	20-40	10-25	15-30	5-15
Residential Community	2-8	8-15	3-10	2-5	10-30	5-15	10-20	2-8
Transportation Hub	5-12	12-25	8-15	4-10	35-45	15-25	20-35	7-12

Table 2 provides a comparison of the application effects of BIM5D technology in different types of construction projects. Compared with traditional construction methods, BIM5D technology has specific benefits in multiple key performance indicators. It not only includes direct benefits such as shortened construction cycles, improved labor productivity, reduced material waste, cost savings, and reduced safety accidents, but also indirect benefits such as reduced design changes, reduced construction conflicts, and increased project profitability.

4.3 Technical Advantages and Limitations

BIM5D technology provides a comprehensive data support platform through an integrated multi-dimensional model. This not only optimizes the construction plan and resource allocation, but also achieves real-time monitoring and control of costs, improving construction efficiency and quality. The BIM5D technology uses the 4D simulation to preview the construction process, which allows project teams to detect and deal with potential constructions conflicts and difficulties prior to construction. The 5D cost analysis function could make the project managers monitor the cost input in real-time, timely adjust the budget, and prevent cost overruns effectively. Nevertheless, the BIM5D technology application still has some limitations. First of all, in terms of technology maturity, due to the continuous development of the BIM5D technology, there are still some issues related to incomplete software functionality and compatibility. Besides, some consulting companies do not fully understand the technical demands of BIM5D technology and have not made full use of the value of the BIM5D technology in the management of construction, which has caused an inadequate investment. And the policy and regulation support may not be complete enough in some areas, which has affected the development of the BIM5D technology. The application of BIM5D technology invests more cost and time, and the initial investment may not be good enough for some projects, thus it may affect the project managers' decision-making in applying the BIM5D technology.

5. Conclusions

This article studies the application of BIM5D technology in the construction of super high-rise buildings. BIM5D technology provides a comprehensive data support platform for construction project management by integrating three-dimensional geometric model, time, cost and other multi-dimensional information. This improves the construction efficiency and quality control, and realizes cost saving.

This article also emphasizes the advantages of using BIM5D technology to build super high-rise buildings. However, there are some limitations in its application. In terms of technical maturity, BIM5D technology is still developing, and there are problems of incomplete, incompatible and incomplete software. In addition, some enterprises have insufficient understanding and investment in BIM5D technology, and some local policies and regulations are not in place. In addition, the implementation of BIM5D technology requires additional cost and time investment, and for some projects, the initial investment return may not be significant. The development and maturity of BIM5D technology can make it more successful in controlling project cost. Through the improvement and popularization of technology, it is helpful to solve the existing problems mentioned in this article, thus improving the practicability and universality of BIM5D technology.

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References

[1] Tian Wei, Ma Junjie, Zhang Xuqiao, Cheng Loufeng. Research on the control technology of vertical deformation difference in the construction process of super high-rise buildings [J].Architectural Structure, 2024, 54(2):41-46

[2] Ren Hao, Wang Xianjie, Zhang Linfei, Weng Zhenjiang, Gao Xuelian, Chen Yongdang. Fire prediction, fire simulation and evacuation of personnel in the construction of super high-rise buildings [J].Science, Technology and Engineering, 2024, 24(12):5114-5122

[3] Xu Ping. Research on monitoring technology of the whole process of construction of super high-rise buildings [J].Construction, 2024, 46(3):354-356

[4] Ma Zhipeng, Feng Huailing, Wu Dawei. Research on the technology of push-pull sliding protective shielding frame for the construction of super high-rise buildings [J].Construction, 2024, 46(5):770-772

[5] Xiang Miao, Xu Liang, Wang Daqing. Analysis of the seismic effect of supporting pressure-bearing structures in deep foundation pits in the construction of super high-rise buildings [J].Construction, 2023,45(1):209-212

[6] Szołomicki J, Golasz-Szołomicka H. Analysis of technical problems in modern super-slim high-rise residential buildings [J]. Budownictwo i Architektura, 2021, 20(1): 083-116.

[7] Wu X, Guo Z, Liu L, et al. Seismic monitoring of super high-rise building using ambient noise with dense seismic array[J]. Seismological Research Letters, 2021, 92(1): 396-407.

[8] Ilgın H E. Space efficiency in contemporary supertall residential buildings[J]. Architecture, 2021, 1(1): 25-37.

[9] Kalantari S, Shepley M. Psychological and social impacts of high-rise buildings: A review of the post-occupancy evaluation literature[J]. Housing studies, 2021, 36(8): 1147-1176.

[10] Bazhenov Y, Murtazaev S, Bataev D, et al. High-strength concretes based on anthropogenic raw materials for earthquake resistant high-rise construction[J]. Engineering Solid Mechanics, 2021, 9(3): 335-346.

[11] Kun P, Esa M, Munianday P. Optimizing Construction Cost Control through BIM5D Digitalization: A Case Study on the Application of Glodon Software in China[J]. Journal of Advanced Research in Applied Sciences and Engineering Technology, 2023, 32(2): 487-507.

[12] Cao Y, Wu X, Feng Z, et al. Research on Collaborative Management of Project Safety and Quality Based on BIM 5D [J]. Journal of Information Technologyin Civil Engineering and Architecture, 2024, 16(1): 116-121.

[13] Roman A, Andrii S, Galyna R, et al. Integration of data flows of the construction project life cycle to create a digital enterprise based on building information modeling[J]. International Journal of Emerging Technology and Advanced Engineering, 2022, 12(1): 40-50.

[14] Ershadi M, Jefferies M, Davis P, et al. Implementation of Building Information Modelling in infrastructure construction projects: a study of dimensions and strategies[J]. International Journal of Information Systems and Project Management, 2021, 9(4): 43-59.

[15] Z Lv, X Li, H Lv and W Xiu. BIM Big Data Storage in WebVRGIS. IEEE Transactions on Industrial Informatics, 2019, 16(4): 2566-2573.