A Comprehensive Application of BIM Modelling for Semi-underground Public Architecture

A Study for Tiantian Square Complex, Wuhan, China

Yi He [1], Marc Aurel Schnabel [2], Rong Chen [3], Ning Wang [4]

[1, 2] Victoria University of Wellington
[1, 2] {harry.he|marcaurel.schnabel}@vuw.ac.nz
[3, 4] Changjiang Survey Planning Design and Research Co., Ltd.
[3, 4] {rongchen|ningwang}@cjwsjy.com.cn

Abstract. The paper presents research on how Building Information Modelling (BIM) can be applied comprehensively throughout the design of an architectural project. A practical method based on BIM models that help to deal with multidisciplinary issues by integrating the design information from different sources, collaborators and project stages is formulated by adopting existing available tools. The 'Tiantian Square' building project in Wuhan, China combines a subway station with a commercial hug. According to the project's size and complexity, our study focuses on the multiple cooperation of professionals from different backgrounds, including the departments of architectural design, structure (civil engineering), HVAC (Heating, Ventilation and Air Conditioning), water supply and drainage, and electrics and sustainable design. Our paper presents how the BIM model bridges between various simulation platforms through our technical system and management, including steps of transformation, simplification, analysis, reaction and improvement. Our research has helped to improve the overall efficiency and quality of the project. We generated a successful analysis-design approach for the initial design stages, which does not require in-depth analysis. It is a practical method to immediately evaluate the performance for each design alternative and provide guidelines for design modification. Finally, we discuss how the coordination of different department becomes a crucial factor as we look forward to a more open, communicative and inter-relational design and development process.

Keywords: BIM, Subway Complex, Simulation, Semi-Underground Architecture

1 Introduction

BIM is widely used for accomplishing various design related tasks in an efficient manner [1]. The information within the building information of the BIM model can be shared and reused by different professionals to analyse for optimisation.

The ‘Tiantian Square’ project is an actual life project that includes complicated functions of commerce and transport transfers. It is an important subway station being the junction of Line 8 and 10 of Wuhan Subway System. Due to its high complexity, the project requires multiple cooperations of professionals from different fields. Therefore, building information modelling is even applied from the early stage in the design process.

The project is located at the junction of the Fazhan Road and Wuhan Road in Jiangan District. Above it is the Zhuyeshan Overpass. Under the complex lies the Huangxiaohe Tunnel. The project covers an area of 3.3 hm^2, with an architectural area of 28,062m^2, including the commercial part of 15,769m^2, the parking area of 10,303m^2, and the equipment area of 851m^2. The area of the buildings above ground is 1,139m^2. The landscape covers an area of 31,108m^2. The main architecture is a 3-storeys underground building.

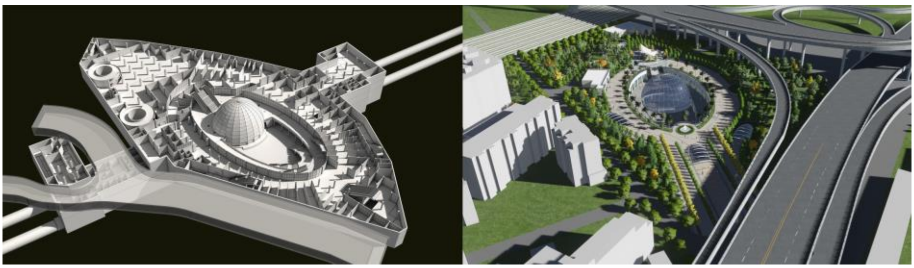

Fig. 1. The 3D model based on BIM of the project of Tiantian Square Complex

The challenges of this project lie in its complexity and design requirements and the limitation of the site. The architecture has been designed as a semi-underground type for providing more public green space and avoiding influence to surrounding buildings. The achievement of complex functions needs multidisciplinary cooperation. Therefore, a practical method based on BIM models that help to deal with multidisciplinary issues by integrating the design information from different sources, collaborators and project stages is formulated by adopting existing mature and reliable tools.

Our target is to make the project design process comprehensive enough that it considers all the aspects including the sustainable design for architecture, the structure design, civil engineering, and equipment arrangement. Collaborative design is needed to enhance design communication and improve the design efficiency [2]. The aim, firstly, is preventing the generation of errors at an early stage by strengthening the design information sharing. Secondly, as this is a complex project and design time is limited, we intend to promote the efficiency to shorten the design time. Thirdly, analysis and optimisation are needed to maintain or even improve the design quality compared to the previous projects.

2 Design Strategy

According to the aims discussed, the design prototypes have to be simulated on different software platforms. The calculation results can be the reference for the design. The transition from the paper-based exchange of design models to processes based on the use of digital models represents an important shift in the design and construction industry. Using digital models opens the possibility of automating a number of the analyses done during design, with significant consequences for the speed and efficiency of the design process, and for the quality of the resultant designs [3]. In an industry so heavily dependent on collaboration, challenges of interoperability must be addressed to maximise these benefits.

2.1 Project management

The BIM leading group and design team are founded to guide the departments of architecture, structure, water supply and drainage, HVAC (Heating, Ventilation and Air Conditioning), electric and sustainability [4]. 3D collaborate design mode has been set up by creating the centre model and working set. Models from different departments contribute to the centre model. Its information can be shared and modified in real time. Then, the information from BIM models is used for further analysis.

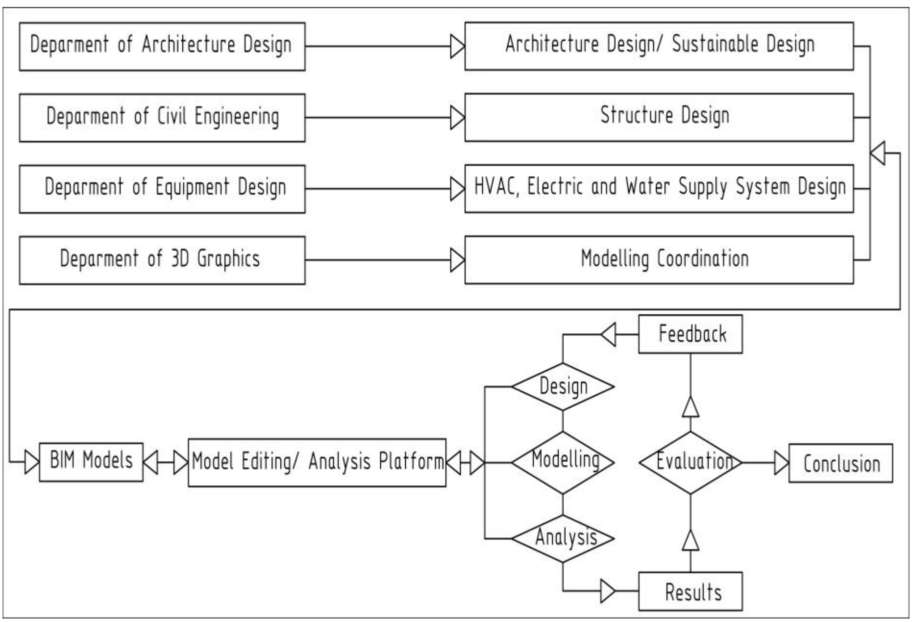

Fig. 2. The graph shows the project design workflow based on BIM

2.2 Analysis and Optimisation Methodology

For sustainable design, architectural performance such as daylighting, wind environment are studied. Previous sustainability analyses may require the establishment of new models because of the software environments. The simulation times are usually long, and models are hard to modify in some platforms. Therefore, this can be complicated and time-consuming, which affects the efficiency of architecture design process. In our study, we propose an alternative iterative approach to explore the issue by using a parametric performance analysis based on graphic and associated models. As the models are generated by a parametric method, they can be easily modified by changing their parameters. This modelling-to-analysis process can be repeated to compare the performance of models with different parameters. From this comparison and circulation, feedback can be generated. Accordingly, optimised design can be concluded. In this process, BIM models are sometimes transferred to different formats depending on the simulation platforms for analysis (Fig. 2). To be specific, for architectural design, as there are more analysis tool resources for *Rhinoceros 3D* (Rhino) software and *Grasshopper3D* (*GH*), and early-stage design is usually done in the environment, BIM models are sometimes imported to *Rhino* for further simulation. Moreover, the optimisation result will be reflected in the BIM models eventually.

Table 1. The table presents the adopted software tools, their users and functions

Users	Software	Functions
Architectural Designers	Revit (Architecture)	BIM models setting up
	Rhino/ Grasshopper	Parametric Modelling for Early-Stage design
	DIVA for Rhino	Daylighting and Illuminance Analysis
	Vasari	Wind Environment Study
	Ecotect	Daylighting Analysis; Sound Performance Analysis
	Tianzheng	Design Drawing
	Flow Simulation	Wind Environment Study
Structure Engineers	Explorer	Structure Analysis in Revit
	PKPM	Structure Design
	Revit (Structure)	BIM models setting up
	AutoCAD	2D Drawing
Equipment Engineers	Revit (Equipment)	BIM models setting up; Installation Simulation
	AutoCAD	Design Drawing

Furthermore, for civil engineering, the structure is analysed; for HVAC, electric, water supply and drainage, equipment installation can be simulated, cables and pipelines collisions can be detected. According to analysis feedback, optimisation can be implemented by editing the models in every aspect from different departments. Because of the parallelism of improvement, this increases the efficiency of the architecture design process.

3 The Modelling Process

For the modelling process which includes the main body of the architecture and its detailed parts, we employed *Autodesk Revit*, *Rhino* and *GH*. In the case of a complex application such as sustainable analysis, conversion processes are often involved in the modelling.

For this project, the major part of the modelling has been done in Revit. The model is divided into several child models which are connected to the main model. Several parts of the design are developed by different departments of the architectural firm. Then the parts are all assembled into a complete 3D model.

The sustainable design is mainly done in the other software environments such as *Rhino* and its plug-ins. So we convert the BIM models to the format that can be edited by *Rhino*. Before import, the models are simplified to reduce the computing needs of the software. The models are modified further in *Rhino* to fit the analysis environment. The reasons for doing so are: first, this can improve the analysis efficiency; second, in this case of sustainable analysis, physical and graphical information are the major part needed from the BIM models.

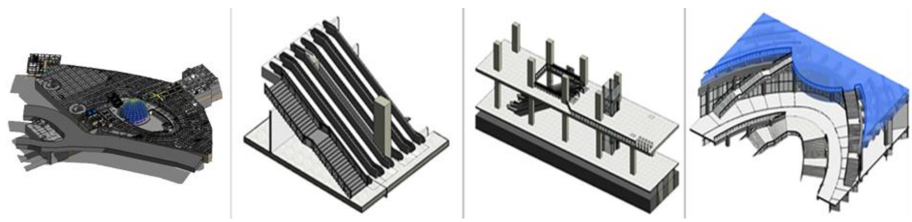

Fig. 3. Models of architectural components set up in BIM system. From left to right, they are the complex's main body, the escalator, the railway platform, and the atrium respectively

The modelling of specific detailed parts can be done in the environment of *Rhino* and *GH* [5]. For the generation of the reproducible works, using the parametric method is efficient and suitable for comparative research. Our novel approach is to generate the single components first, and then assemble them together. For the specific modelling such as the facade, the main strategy is to create the arrangement of points to locate the positions of its components. Then the shape of the components can be defined by using certain algorithms before attaching them to the location. For example, we can use the array algorithm in the *GH* to create a group of points. The horizontal and vertical number of the points can be defined by the inputs related to integer parameters. Then we use the move command to duplicate the components by attaching them to the array of location points. The generation process at this stage is not complicated, but it has the advantage in adjustments of the components arrangement, which is suitable for iteration simulations and analysis.

Moreover, this method can provide the significant potentials that allow us to create complex models and analyse them further by modifying the algorithms adopting different modules.

4 Sustainable Design based on BIM

For this project, we use BIM and parametric modelling methodologies paired with a simplified performance calculation method to assist our design. It is the first time we make use of this methodology in an architectural project. From our experience, this methodology not only offers benefits during the design phase but also further down the track during construction and management [6]. From the beginning, aspects of sustainability have been taken into consideration. Information about local climate, the existing circumstance of the site and architectural standards especially the *Green Building Standard* are included in the initial analysis. In communication with clients, requirements, specific functions and expected performance are determined to guide the initial design phase. During this, several analysis models have been generated.

4.1 Daylighting Analysis

The daylighting analysis strategy is to analyse the objects from large scale to small scale, from overall study to detailed study. The daylighting performance of the architecture has been investigated from the site to the façade, from the outdoor to the indoor environment [6]. The overall situation of the project including the site has been simulated first. The aim is to find out the time when the outdoor environment is covered by direct sunlight on specific days such as the winter solstice. It can be done in the Revit using its daylighting analysis function. The sun orbit of the whole year can be shown. Then the caused shadow can be simulated to find out the architectures which obscure each other. To study it further, we used a plug-in called *Daylighting Calculation* in '*Tianzheng Architecture*', which is a widely-used CAD software platform developed by a Chinese company. In its environment, the graphic information such as height and shape can be taken into consideration in the analysis process. The software tool can calculate the solar irradiance time of every area of outdoor space at any height on any day of the whole year.
Then detailed analysis has been implemented. In this session, we would like to study the indoor illuminance performance of the architecture, especially the design strategies that mean to allow more daylight into the indoor environment. First, the graphic information of the BIM models has been selected, exported and modified for the analysis system. The model has to be simplified or rebuilt according to the tools we selected. As introduced above, an atrium has been designed to let natural light can reach the sub-basement; the glass dome set in the middle of the atrium is aimed to allow more daylight into the architecture; increase the area of the windows on the façade properly. Our analysis has proved the effectiveness of these design steps. After

the simulation, we improved the design of the façade, the atrium, the dome through minor modification. The analysis tool of *Ecotect* has been used first (Fig. 4.). As its calculation is based on the daylight factors, and to make our simulation more accurate, the software of '*DIVA*' which is an optimised daylighting and energy modelling plug-in for *Rhino*, has been introduced to repeat the analysis [5]. According to the result, we can confirm that our design can surely improve the indoor illuminance. Exploring this possibility another analysis tool of '*PKPM*' has been used to calculate the daylighting and especially the glare performance. The analysis is necessary, as the architectural design is required to meet certain standards. It is part of the evaluation of the whole project that a report has been generated for the authorities.

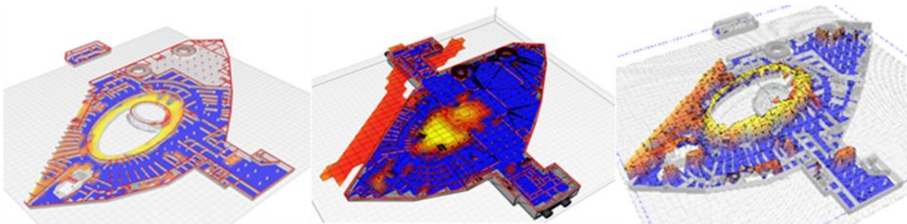

Fig. 4. On the left, the image is the illuminance analysis of Basement Level 1. In the middle, the image shows the analysis of Basement Level 2; on the right, the image shows the 3D display of the illuminance value of the Basement Level 1

4.2 Wind Environment Analysis

The designed atrium cannot only allow more natural light into the architecture but can also provide better natural ventilation performance. As we know, isolated by the soil cover, underground architectures have the difficulty of exchanging the indoor and outdoor air without artificial ventilation instruments. The atrium has provided a bridge to connect the indoor and outdoor space.

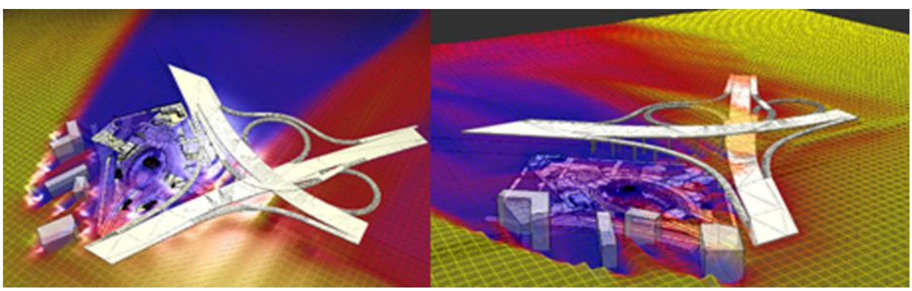

Fig. 5. The images illustrate the wind environment analysis based on BIM

To prove the design effectiveness, the software tool of *Autodesk Vasari* has been applied to analyse the wind environment (Fig. 5). *Vasari* used to be an instrument to assist sustainable design, which can analyse the daylighting, energy and wind environment. However, it is not supported anymore. The advantages of *Vasari* include its simple way of operation and the rapid analysis speed. It can reduce the analysis time remarkably and efficiently give a response to designers and engineers. Another advantage of *Vasari* has been its friendly environment to BIM models built up from *Revit*. The models do not need much modification before being imported to the software. In this case, the model of the complex is mainly simplified before analysis. With the consideration of the local climate, parameters such as wind speed and its direction have been set to certain values. Different situations according to various seasons have been simulated. There are mainly two study objects: (1) the interaction between the complex project and the site; (2) whether the design of atrium can introduce more airflow to the space and the façade. In the site, there are not many buildings in the surrounding area. However, there are several viaducts beside the complex. To find out whether the viaducts will affect the complex, their influence has been studied. The results have shown the influence is relatively rare not only from the viaducts to the complex but also from the complex to the viaducts and other architectures. It is believed the semi-underground form of the project would hardly impede the natural ventilation in the district.

As *Vasari* is inaccurate in its calculations, we undertook further studies to cross check *Vasari*'s results. Some tools like *Fluent*, *Phonics*, or *Flow Simulation*, which are plug-ins for *SolidWorks*, can be applied to verify the results. Moreover, we were able to ensure the effectiveness of our design.

4.3 Acoustic Performance Analysis

Though an acoustic study is not required by the client or any authorities and standards, in this case, we still take it into consideration as a test of one part of the workflow. It not only tests our system but also improves the acoustic performance of the architecture and accumulate research experience in this field. For architectural acoustics, two factors have been mainly considered (Fig. 6.): one is the noise control; another one is the reverberation time in the architecture, which includes space in the atrium and the glass dome.

For the noise control research, we mainly study the influence from surrounding environment and how it affects the complex. After a preliminary inspection, the main noise source comes from the vehicles on the viaducts. A parametric method has been applied to calculate the closest distance within the viaducts and the complex. Then the noise source point has been set in the model analysed by *Ecotect*. After this, the simulation of the noise attenuation can be done, from where we find out the noise intensity has been remarkably reduced to a certain degree before they reach the architecture. So the study can confirm that the noise would not affect the architecture. Moreover, as it is a semi-underground building, the influence will be weakened further.

As mentioned, the complex is a semi-underground architecture with the atrium and the dome in the middle. The space in the atrium surrounded by the façade is semi-isolated. This kind of form can cause an echo in the space. To the buildings like theatres or concert hall, the generation of echo has to be controlled; the reverberation coefficient is designed to be restricted in a certain extent. In this case, as the complex is a public architecture that includes the functions of commerce, subway station, such sound performance is not required. Still, the reverberation coefficients in the atrium and glass dome have been calculated spiritedly.

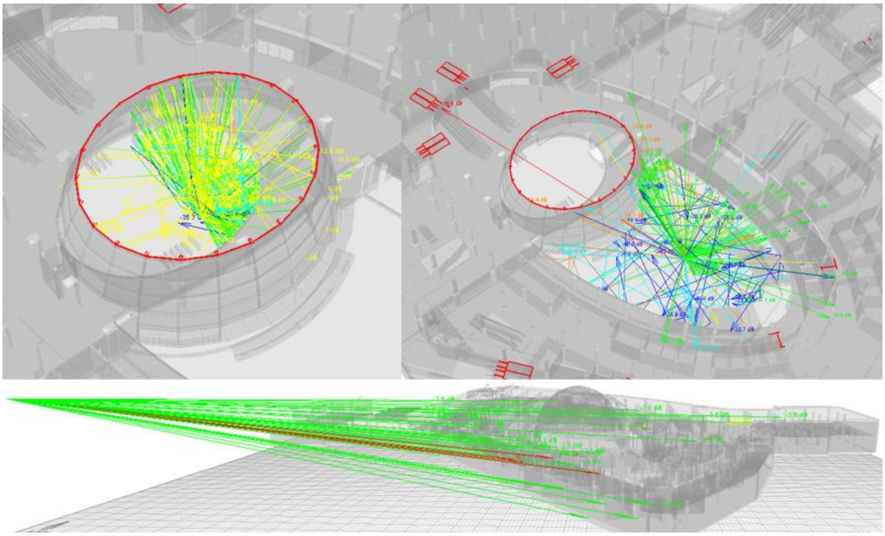

Fig. 6. The models illustrate the acoustic performance analysis: Top-left shows the reverberation simulation in the glass dome; top-right shows the reverberation simulation in the atrium, and the bottom figure shows the noise analysis

5 Civil Engineering and Equipment Installation

The department of civil engineering has taken charge of the structure design. For electronics and water supply, designs are by the equipment design department. After the preliminary architectural design has been proposed, the design information can be shared through the BIM system. The architectural department can communicate with the civil engineering department and the equipment design department using the BIM models. These two departments can start their own design tasks efficiently.

For the structure design, the civil engineering department has completed their design applying the structure function in Revit (Fig. 7.). At the same time, they have analysed the design using a new plug-in in the same environment, called *Explorer* invented by a Chinese company. Then, the BIM models have been exported to PKPM, which is a normal software for structure calculation in this field. In there, the model is simulated further.

For the electronics and water supply, the equipment design department will usually face problems of installation of the instrument, cables and water pipes. In the design stage, for example, the position of a certain cable may be blocked by another water pipe without noticing that the system is too complicated. Finding and correcting such conflicts usually, take a long time. In this project, BIM models have changed the situation as the software is capable of checking every installation. The influence of the structure and architecture design will also be considered so that the problem such as a water pipe being struck by a beam can be avoided from the beginning.

Besides the application in the structure and equipment design, the technology also helps in the fabrication process. As the glass entrance of the subway station and glass dome are manufactured in the factory, our parametric modelling based on BIM can assist to decide the sizes of the components and locate the positions of them accurately.

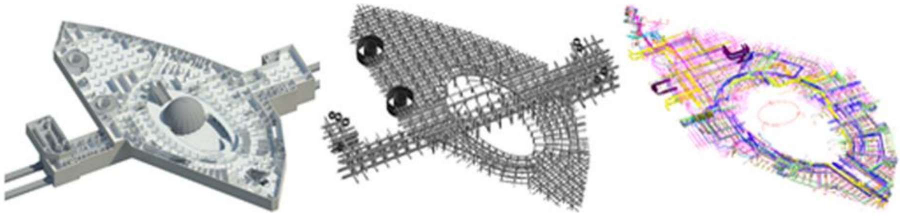

Fig. 7. The figure on the left shows the model from architecture department; the figure in the middle shows the structure design; the figure on the right shows the models of pipes, cables and instrument developed by the equipment design department

6 Design Result

For the semi-underground architecture, our study has helped in architectural design, sustainable design, structure design, equipment design and even the fabrication process. The outcome from the sustainable design such as daylighting analysis and wind environment study has proved that the architecture can meet certain standards. Moreover, the further analysis and optimisation have made the design exceeded the requirement. It will surely let the project get a higher score in the green building assessment in China. Now, the design has passed through the evaluation from certain authorities. Moreover, the complex is already under construction.

Also, our study has helped to improve the design efficiency and quality of the project. It has suggested an alternative analysis approach in the early design stages and put it into practice. By setting up the link of the graph-based system and associative system, we try to take the best advantage of the BIM models for multiple applications, which let us have developed a more advanced BIM-based methodology for practical architecture design projects in the future.

7 Discussion and Conclusion

This study has proposed a novel methodology and workflow to evaluate and analyse the performance in multiple aspects of the semi-underground architectures. A practical method based on BIM models that help to deal with multidisciplinary issues by integrating the design information from different sources, collaborators and project stages is formulated by adopting existing available tools. Though the technologies adopted may not be cutting-edge ones, they are efficient enough to solve problems. It is believed that, because of its generality, it can be universally applied in other architectural design. The simulation we have done is not common in-depth one, but a practical method to immediately evaluate the performance for each design alternative and provide guidelines for modification on the early design stage. The simulation approach is based on both the associative and graph-based models. In sum, the contribution can be summarised as follows.

First, based on our research outcomes, the design strategy we proposed for the semi-underground architecture at the beginning can get certified and improved. We can give our design guidelines to the following similar projects such as subway station complexes. As the models are developed on parametric computational platforms can seamlessly be employed to construction and maintenance stages.

Second, the study has attempted to explore a parametric design-analysis workflow to determine the advantages of parametric design in studying real-time changes in building design. Compared to conventional workflow, it is more easily possible to design a performative-responsive façade using parametric design. It allows for efficient editing the model in any stage of the design process. With the established relationships between parameters in parametric design, architects have better dominance on the project.

Third, our study has developed an alternative approach to accomplish the architecture design, sustainable design, structure design, and equipment design by using a parametric performance analysis. This modelling-to-analysis process can be repeated efficiently to compare the performance of models with different parameters. Based on comparison and circulation, optimised design can be concluded according to the feedback. By setting up the link of the graph-based system and associative system, we have been able to take the best advantage of the BIM models for multiple uses.

Acknowledgements. The research project has been supported by the Changjiang Survey Planning Design & Research Co., Ltd (No. CX2015Z08). The project of The Tiantian Square Complex has won The 3rd Class Prize of the 2nd BIM Design Competition of Exploration & Design Association of Hubei Province (EDAHB), China, in December 2014.

References

1. Eastman, C., et al.: BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors. Wiley Publishing, 101-102 (2008)
2. Wu, C., Fan, Y., Xiao, D.: Computer Integrated Manufacturing, Handbook of Industrial Engineering: Technology and Operations Management, Third Edition. John Wiley & Sons, Inc. 3-35 (2007)
3. Sebastian, R., Haak, W., and Vos, E.: BIM application for integrated design and engineering in small-scale housing development: a pilot project in The Netherlands. Journal of Neural Transmission General 120(12): 1709-1715 (2009)
4. He, Y. and Schnabel, M. A.: Computational Architectural Integrated Implementation: A Digital Process from Initial Design to Fabrication, in F. Moreira da Silva, H. Bartolo, P.

Bartolo, R. Almendra, F. Roseta, H. Amorim Almeida, A. C. Lemos (eds.), Challenges for Technology Innovation: An Agenda for the Future, CRC Press, Taylor & Francis, London, 435-439 (2017)
5. He, Y. and Schnabel, M. A.: Daylight illuminance calculation model and process for Building Integrated Photovoltaics (BIPV) Systems, in J. Zuo, L. Daniel, V. Soebarto (eds.), Fifty Years Later: Revisiting the Role of Architectural Science in Design and Practice: 50th International Conference of the Architectural Science Association, Adelaide, 389–396 (2016)
6. He, Y., Chen, M., Wang, X., A Brief Discussion and Analysis on Methods of High-Performance Architecture Facades Design, Advanced Materials Research Vols. 368-373(2012), 3757-3760 (2011)