BIM Application
To
Enhance the Quality
Of
Project Management
For
Building Owners and Developers

Fang Fang

Dissertation submitted in partial fulfillment of the requirements for the award of
Degree of Master Research
In
Innovative BIM Evolutionary Research Studies

Supervisor:
Dr Ali Cheshmehzangi, Dr Byung Gyoo Kang, Dr Robin Wilson

Department of Architecture and Built Environment
University of Nottingham Ningbo China

ABSTRACT

In the last 30 years, China's real estate has developed very rapidly. According to the market competition and demand, the owners and developers realize that the project management, which applies the information of consulting, design, implementation, and operations, should be more standardized.

With the maturity of construction technology and the continuous updating of digital technology, e.g. Building Information Modelling (BIM), the trend to enter into a digital world is becoming widely accepted by the AEC (Architecture, Engineering and Construction) sectors. The perspective of owners and developers in project management includes cost, schedule, quality and safety. Each element shall establish corresponding goals at the initial stage of the project.

The aim of this research is to establish a revised workflow for a typical construction project, which is combined with the BIM applications. In order to make all of participants understand and apply these workflows, the corresponding specifications of BIM application were established in this research, which is included the employer's information requirements, common data environment requirements, model content, and standards. After initial investigation of the current BIM application in China and the BIM standard of BSI by UK, these specifications are considered to be very suitable for mix-used commercial project. At the same time, the new workflow for the project management will be followed and the optimization of the new workflow will be tracked in the processing of coming new project. This will be the next research in the future.

DECLARATION

I, Fang Fang, certify that this is my own research, and it has not previously been submitted for any assessed qualification. I certify that the use of material from other sources has been properly and fully acknowledged in the content. I understand that the normal consequences of cheating in any element of an examination, if proven and in the absence of mitigating circumstances, is that the examiners 'Meeting be directed to fail the candidate in the examination as a whole'.

Fang Fang

ACKNOWLEDGEMENTS

I wish to acknowledge the contribution that the following people have made to the completion of this dissertation.

Thanks to Dr Ali Cheshmehzangi, my dissertation supervisor for his faith in me, his valuable advice and his experience in the chosen topic of this research to help me complete this dissertation.

I would like to thank Dr Llewellyn Tang and Mr. Yang Lin for their suggestions about polices of BIM application.

I would also like to thank my parents, my wife and my daughter for their support during my research study period.

CONTENTS

CONTENTS (Cont'd)

BIM Application to Enhance the Quality of Project Management For Building Owners and Developers

List of Figures

BIM Application to Enhance the Quality of Project Management For Building Owners and Developers

List of Tables

BIM Application to Enhance the Quality of Project Management for Building Owners and Developers

Chapter 1 Introduction

1.1 Introduction

In the last 30 years, China's real estate has developed very rapidly. This has mainly occurred due to higher investment in real estate that has shown to be more profitable over the years. According to the market competition and request, the owners and developers realize that the project management, which applies the information of consulting, design, implementation, and operations, should be more reasonable and standardized. Hence, there is still a large demand for this process of standardization in the industry.

Industries such as manufacturing and finance have been automated, driving enormous gains in productivity worldwide. However, during the same period, the conventional practice in architecture, engineering, and construction (AEC) remain very much dependent on professional experiences of individual members, especially in the construction phase.

With the maturity of construction technology and the continuous updating of IT technology, building information modelling (BIM) is accepted by more scholars and practitioners of the AEC industries (B7, W1), particularly through its information visualization that is increasingly appreciated by associated industries. Migilinskas had researched the benefits, obstacles and problems of practical BIM implementation in 2013 [1]. It revealed that it was saved ~20% of time for plan and view drawing with AutoCAD and time for redrawing with mistakes correction when changes occur. CzmochMain demonstrated the difficulties during the implementation of the BIM technology and how they were related to the potential benefits [2]. Bargstädt, the professor for construction engineering and management at Bauhaus-Universität Weimar, had also illustrated the challenges of BIM for construction site operations [3]. The development of BIM tools that allow

to implement BIM-based design change management in an efficient way seems to be both actual and challenging task. Such functionalities as quantifying, visualizing and analyzing changes made to models would provide benefits for all participants of the construction project [4].

This last decade has witnessed a rise in benefits that are brought by the application of BIM, such as conflict between drawings that has been found before confirming the drawings, as well as accurate quantities have been automatically calculated by computers and computational modelling techniques. During the same era, many countries have promoted BIM research and its application in AEC industries. The research of Fazli revealed that BIM can help project managers in the task of delivering successful projects in Iranian construction industry [5]. Ahmad explores the role of BIM in optimizing building design for sustainability in his research [6]. Getuli demonstrates some case studies about the BIM-based code checking for construction health and safety in Italy. He points out that the parametric rule-set could be applied in various projects with a significant return of investment and promoting workflow standardization for both the Public Client and the Design and Construction teams [7]. In some countries, these are introduced earlier, such as in the US, the UK, Singapore, Japan, and so on. Meanwhile in China, the Ministry of Housing and Urban-Rural Development (MOHURD) of the People's Republic of China has issued guidance of promoting the application of BIM in AEC projects [8]. This guidance elaborates on the objective of different participants of the projects, such as the project owner, geological survey consultant, design consultant, general contractor, and so on.

In addition, there are many examples of how BIM has become increasingly important in the AEC industries. Examples of these include: The designer reduces design errors through modelling conflict. The construction enterprise reduced construction material waste through modelling. The owner is the most pertinent participant in the BIM process. The optimization results brought by BIM application to project management will eventually be translated into the improvement of management efficiency of developers, including effective cost control, schedule optimization and so on. Furthermore, BIM as a collaborative process that facilitates the sustained logistics of information is introduced as viable way of bridging the

gap identified earlier [9]. Traditionally, three criterion of time, cost, and quality have been major indicators of project success in the project management society. Other factors such as profitability, technical performance, functionality, health and safety, productivity, and environmental sustainability, are also important aspects for evaluation in order to determine project success[10]. Therefore, the overall project management processing is the significant factor for the success of project completion and delivery. In this regard, the workflow, which includes all participants and specifications, is the guidance for the project management. Thus, it plays a major part in better delivery and optimization of the overall project management (PM).

This study introduces the traditional workflow of project management for a typical mix-used commercial project as a case study. This study aims to highlight problems of current workflow supported by further assessment. Consequently, the study also aims to optimize the project workflow by adapting to future digital project management combined with BIM applications and development of specifications for BIM application in this system. The proposed and revised workflow is then expected to be used in the new mix-used commercial project, which will be trialed as a real-life pilot project. This will be the next step of research in the future. The findings from the study will have novel practical implications and recommendation for the optimisation of the current project management practice. To further verify the results, the prospective for application of BIM will be introduced as part of enhancing the quality of project management in the future. According to the literature, most researchers focus on the applications and the challenges of BIM. In project management, the combination of workflow and BIM application and how the corresponding specifications of modeling adapt to different workflows are ignored. Therefore, this research aims to revise the traditional workflow of project management combined with the BIM applications.

1.2 Point of departure

To better evaluate what is aimed to be studied here, it is important to first provide some clarifications of concepts. The following sub-sections highlights these key definitions of the study.

1.2.1 Client

The study considers the client, which is the developer of a real-life mix-used commercial project. The strategies of workflows and the specifications of BIM applications are based on the viewpoint of the client.

1.2.2 Workflow

In the process of project management, workflow is the method and requirement to guide all participants to work for the same objectives, including but not limited to clients, contractors, consultants, etc. During different period of project flow and for the different functions, we need to develop the corresponding workflow. The workflow mentioned in this research includes the main workflow of cost management, schedule management, and quality management.

1.2.3 Specifications of BIM

Based on the research on the application of BIM in China market, the requirements of project management process suitable for optimization, including the standards of modelling delivery and BIM application results report, are formulated on the basis of the BIM specification of BSI in the UK and the specifications issued by the Chinese government. First of all, some contents should be defined according to the specifications, such as the client, contractor, consultant and so on. All the participants in the project should apply the BIM applications based on the same concept.

1.2.4 Definition

a. Client

The person or organization pays money to another organization in return for a project. I have also used the terms “owners”, “stakeholders” and “developers” in this context. However, in many current project management, the proxy construction company acts as the consultant of the developer, playing the role of the project manager. It can also be considered as the client. The only difference is that consultants need to report regularly to the real owners about the progress of the project, including cost and schedule. And some

decisions need to be confirmed by the clients' board.

b. Contractor

A construction company that is responsible for the construction and execution of the project according to the schedule, cost, quality and safety requirements of the owner through legal means. In addition to general contractor, there are usually some professional sub-contractor, such as curtain wall, interior decoration, landscape, and so on, which also belong to the contractors referred to in this context.

c. Consultant

Consultants refer to persons or organizations that have professional ability to provide design, construction, quantity survey, inspection and other services for owners during the construction period. For example, architectural design, interior design, curtain wall and so on.

d. Mix-used commercial project

Mix-used commercial projects usually include office, commercial (retail, food and beverages, entertainment functions), residential and other forms of business. Generally, the number of project components, degree of activeness within each component, degree of interactions between project components, and interactions of the project with entities outside of the project were frequently considered as the attributes that create complexity of a project. [11]

Mix-used commercial projects usually involve more contractors, suppliers and consultants. Therefore, appropriate workflow is the basis of high-quality project management. It can coordinate and organize the work of different units and personnel to achieve the project objectives set by the client.

e. Main factors of project management

In mix-used commercial project, the client usually pay attention to 4 facets: cost, time, quality and safety. There are lots of risks in these

facets. The budget is out of controlling. The time schedule delay. The quality of the construction cannot conform to the mandatory standards. The loss of profit and the wastage of the cost will come out due to these problems.

1.3 Research Aims and Objectives

According to the working experience and the case study about the project management, this research will investigate and reveal the traditional workflow for the processing of the lifecycle in the mix-used project. The client usually focuses on the cost, time and quality requirements of the project. But in reality, the accuracy of drawings cannot match the standard due to the error of information communication. In the process of using these workflows for project management, there will be deviations. Consequently, it will bring about negative impacts on cost, time and quality control. These are the common issues that need to be addressed throughout the project management process.

On the other hand, because BIM applications are still at the initial stage, designers and contractors pay more attention to the functions of design optimization and simulation brought by the BIM applications, while the important applications such as coordination and information sharing in project management have not been paid attention to by the clients. Therefore, the BIM technology has not been applied in the workflows to optimize the quality of project management. This is identified as a remaining gap in practice of project management.

At the same time, after studying the literature of BIM application and the relevant BIM standards, this research finds out that the applications of BIM are usually paid more attention. Zhiliang Ma had researched the integrated application of BIM and GIS.[12] Jiang Xu researched on application of BIM 5D Technology in a project.[13] However, there is no clear definition of BIM application objectives, the specifications and requirements of model making, and coordination method for the project management at the initial stage of the project.

Therefore, the aim of this research project is to define the contents and standards of BIM, optimize the workflows of project management for cost, time and quality

control based on the analysis of traditional workflow and BIM application. As the main objective, this research will create the specifications of modeling for different majors. This leads to revision of the traditional workflow combined with BIM applications. At last, the new workflow will be developed and then applied in a preservation project for experiment and the study will focus on the result of testing for enhancing the quality of project management.

1.4 Research Summary and Structure

This research begins with the literature review including a brief history and the situation of the project management and BIM application. The literature review highlights some of ongoing practice trends and paradigms, as well as highlighting the gaps that will be addressed in this research project. Then, in Chapter 3, the methodology of research will be introduced and provide a holistic view of this research project from the methodological perspective, including methods undertaken for this research and the case study of research. Further in to this research project, Chapter 4 will establish the specification of BIM applications and optimize the workflow of project management due to the case study of mix-used commercial project. This chapter will benefit from the materials covered in Chapters 2 and 3, and through the case study analysis undertaken in this research. Finally, the prospective of the BIM application will be illustrated in Chapter5. These will include future directions in research, as well as highlighting the novelty and contribution of this research to the AEC sector, and in particular for enhancing the quality of project management through the BIM application in practice. This will conclude on some of the key policy and practice implications in the field of research.

Chapter 2 Literature Review

2.1 A brief introduction

In order to establish the method to optimize the quality of project management, this research study will investigate the main factors of traditional project management, BIM specifications and the status of BIM application. Consequently, It aims to find out the method of workflow optimization combined with BIM application in the practice of project management.

First of all, this study focuses on the main tasks of traditional project management, as well as the management methods. Secondly, it will provide a broader understanding of the BIM applications in practice. Then, this study will lead in to an overview of the current BIM specifications that are particularly important and influential to the context of China. Finally, on the basis of these, the main objectives of this study are summarized.

2.2 Project management

Project management is the management discipline that plans, organizes and controls people, money and cash so that projects are completed successfully in spite of all the risks. [B1] Every project is unique. Even if design is duplicated, the construction process will be different due to complexity of external factors and internal management. Although the projects are different in the process of construction management, the principles and methods of project management remain the same. Therefore, the need for project management optimization is essential in the sectors of AEC.

2.2.1 The history of project management

Since ancient times and the beginning of human activity records, there has been construction behavior. Figure 1 presents the history of construction and project management. [B2]

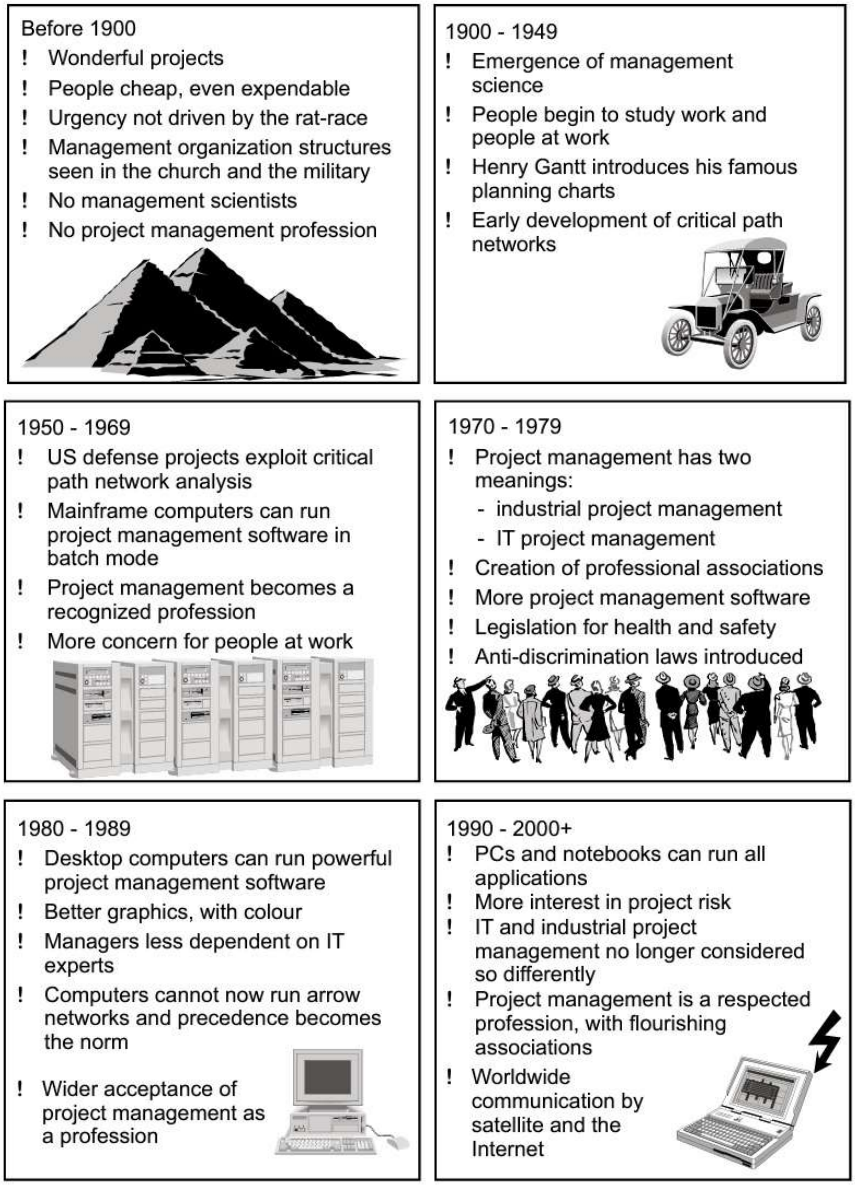


Fig. 1-The history of construction

Source: Dennis Lock, Project Management (tenth edition), Gower Publishing Limited, Page 2, 2013

Project management can be divided into several stages according to the figure.

a. Before 1900, there is no management scientists. Lots of wonderful project usually take the form of the church and the military.
b. Before the 1980s, the concept of project management emerged, from the initial emergency management to the project management developed from industrial projects and IT projects, and gradually began to pay attention to health and safety.
c. When computers become popular and can run more complex management software, the content of project management becomes

richer and more scientific.

2.2.2 Factors of Project Management

There are four types of projects, 1) civil engineering/construction/mining and quarrying, 2) manufacturing, 3) IT projects, and 4) projects associated with management or business change, scientific research. This research focuses on the mix-used commercial project in civil engineering field.

The perspective of the client in the project management includes cost, time, quality and safety. Each element shall establish corresponding goals at the initial stage of the project.

a. Cost objective.

Most projects are undertaken with the expectation of benefits, either on completion or later in their life history. Therefore, strict attention to cost budgets and financial management is usually vital for the overall process of project management and project delivery. Cost management should be considered as a significant facet for the project management. Maruvanchery make use of the Decision Aids for Tunneling (DAT) as an early construction cost and time predicting tool for large-scale underground cavern construction projects and focus on assessing the accuracy of the predicted cost and time for feasibility studies [14]. However, a range of global standards and guidelines have been developed for the project management profession as a whole but there have not been any developments in the field specifically for the project cost management. [15] Although the first Standard Method of Measurement (SMM) of building works had been created in 1922 and developed by the Royal Institution of Chartered Surveyors (RICS)(Williams, Civil Engineering Standard Method of Measurement,1976), the workflow of cost control is gradually improved by the clients or the quantity surveyor consultants based on their experience. And there is no major work standard for mix-used commercial projects.

b. Performance objective

Quality has often been used as an alternative name for the performance project objective. The quality characteristics will depend on the requirements of product, such as specification (including the standard of material and the method of installation), basic safety requirements (which should match the standards issued by supervisor), low operating and maintenance costs.

There is some evaluation system for the Quality system assessment. As Baiburin [16] pointed out in his research report, quality system assessment of the construction participant is generally carried out in an expert way with the use of methods introduced in the Fuzzy Sets Theory. He also analyzed the quality assessment system, which is based on the differentiated, integrated or combined indexes.

In this regard, quality control system is usually issued by the government with a series of principles and requirements, according to which the clients and contractors will compile their own experience for the key performance indicator. In A.I. Romanova's research [17], self-regulation is a favorable environment for doing business, which is characterized by a reduction of administrative barriers for business, and increase the role of the public and professional associations, while ensuring quality control of products (e.g. works, and services). According to the literature, the workflow for the quality control can be revised in this research for the mix-used commercial project, which is based on the BIM application in practice.

c. Time objective

In a common sense, the project progress is required to match the development schedule. And all of the significant stages cannot be later than the proposed original schedule. The risk of the progress usually comes from the abnormal fluctuation of material price, such as steel bar, concrete and so on. On the other hand, the in some occasions, climatic issues and natural disasters may influence the project progress, such as typhoon, earthquake, poor weather

conditions, and so on.

The influential causes of delay investigated are also identified as issues of: corruption, unavailability of utilities at site, inflation/price increases in materials, lack of quality materials, late design and design documents, slow delivery of materials, late in approving and receiving of complete project work, poor site management and performance, late release budget/funds, and ineffective project planning and scheduling successively [18]. Therefore, how to use and optimize a reasonable workflow for schedule management under such complex conditions is one of the purpose of this study.

2.2.3 The relationship between the factors

Cost, quality and time are three key factors in the project management process. Hence, the aim of a project manager must be to achieve success in all aspects of the project. However, the triangle of objectives always appears as conflicting matters in the practice of project management. Mashwama studied the critical success factor for the reduction of cost of poor quality in construction project. It reveals the cost of poor quality.[19]. If quality is prioritised in the project management flow, the cost shall be considered to reserve extra provisional, provided the time maybe last for a longer period. If the cost budget must be controlled during the whole project progress, the quality and the time shall be controlled in the reasonable scope. For example, delay may cost more because of intervening rises in materials prices, salaries and other cost. On the other hand, the financing cost inevitably increases by any associated delay of the construction process.

Therefore, how to combine the three important factors in a unified way and balance the relationship between them must be considered in to the revised workflow for the mix-used commercial project. Hence, the use of BIM application as a recommended method in practice is investigated, adopted and developed further for the specific reason of enhancing the quality of the project management process.

2.3 A Brief of Building Information Modelling (BIM)

BIM was considered as the file that is created by the use of three-dimensional (3-D) computer-aided design (CAD) software programs. [B3] In reality, the most important value of application of BIM is information and how it operates in an information-based approach in practice. It reveals the data that can be used to analyze and predict outcomes throughout different phases of the building lifecycle. For example, in the design stage, it can illustrate the whole picture of the building's information including the dimension and the space as well. If the cost information is input into the model, the cost-sensitive factors can be analyzed by adjusting the design model.

2.3.1 The history of BIM

In 1975, "father of BIM" - Professor Chuck Eastman of Georgia Science and Technology University created the BIM concept that is continuously developed to the current date (W3). The research of BIM technology has gone through three stages: 1) the germination stage, 2) the generation stage, and 3) the development stage. The sprouted of the concept of BIM was affected by the global oil crisis in 1973（www.bimcn.org）. At the time, the whole industry of the United States needed to consider improving the efficiency of the industry. In 1975, Professor Eastman proposed "a computer-based description of-a building" in its research topic "Building Description System", in order to facilitate the realization of construction workers. Process visualization and quantitative analysis improve the efficiency of engineering construction process.

The beginning of design documentation was based on a 2D communication platform [B3]. The designer draws the drawings by hand. With the continuous development of computer technology, CAD instead of man-made drawings, not only improved the efficiency of drawings, but also improved the accuracy of drawings. The 2-D drawings consist of plan and elevation views of the building with details, sections, and specifications. The construction technology is dramatic developed in the last 30 years and major shift is seen in the use of drawings and other assisted tools and techniques. The design of architecture and buildings have, over the years,

progressed to become more innovative with irregular shapes and building configurations, which seemed impossible decades ago. However, there remained some major gaps in information of 2D drawings among the different majors, which also effects the project cost and the detail of construction. Conversely, BIM (3D) reveals the detail of the building construction to the extend it was far too complicated in architectural design. Moreover, it also demonstrates the conflict between the different majors and provides an information-based platform for all. When BIM started to show its obvious advantages, some countries began to promote the application of this technology in their practice.

2.3.2 The BIM policies in different countries

a. In 2006, the US military issued a research plan for application of BIM. Soon after in 2007, the Academy of Architectural Sciences of American (AASA) published The National Building Information Model Standard (NBIMS). Consequently, the Building Smart Alliance took charge of the application research of BIM. At the end of 2008, BSA had the IFC standard, the standards of NBIMS and National CAD, and so on. In the following year, Wisconsin became the first state to require BIM to build public buildings.[20]

b. In the UK, a number of design and construction companies have jointly established the "AEC (UK) BIM standard" project committee and set up "AEC (UK) BIM Standard" as a recommended industry standard (B8). A series of BIM standards have been issued since 2007 as the Table1 (included but not limited).

BS 1192:2007	Collaborative production of architectural, engineering, and construction information - Code of practice
--	AEC BIM Technology Protocol - Practical implementation of BIM for the Architectural, Engineering and Construction industry
PAS1192-2	Specification for information management for the capital/delivery phase of construction project using building information modelling

PAS1192-3	Specification for information management for the operational phase of assets using building information modelling
PAS1192-4	Collaborative production of information, fulfilling employer's information exchange requirements using COBie
PAS1192-5	Specification for security-minded building information modelling, digital built environments and smart asset management
PAS1192-6	Specification for collaborative sharing and use of structured health and safety information using BIM
ISO19650	Organization and digitization of information about buildings and civil engineering works, including building information modelling(BIM)

Tab.1 – BIM standard in UK (Source: adapted from www.bsigroup.com)

These standards define the relevant processes and requirements of the BIM applications, and make good explanations in information requirements, exchange, use and other aspects in order to reduce construction waste and improve construction efficiency. For example, BS 1192:2007 promotes the avoidance of wasteful activities, such as waiting and searching for information, over-production of information with no defined use, over-processing information, simply because the technology can, and defects, caused by poor co-ordination across the graphical and non-graphical data set, which require rework [B4].

c. In 2010, Norway proposed the standard for 2010 Implementation of support for IFD Library in an IFC model. The data based on IFC model exchange had been given and the Information Delivery Manual-IDM standard project had been carried out (B8). The research mainly solves the information exchange requirement of various tasks in the project management.

d. The government of Singapore started the construction information project CORENET (Construction and Real Estate NETwork) as early as

1995, with the aim of linking up the trivial business of the building industry to form a new building system to improve the quality and productivity of the project. In 2000, the Singapore government actively developed the e-Plan Check of the CORENET project on the basis of its existing work to provide automatic checking of IFC drawings. In 2003, the integrated building planning system IBP (Integrated Building Plan) was developed. In 2004, the integrated building service system IBS (Integrated Building Services) was completed. In 2005, the system was successfully implemented by testing, organizing academic conferences, encouraging the use of BIM design methods economically, providing training for the new system, tracking and service in the BIM project.

e. The standard of Japanese construction field information is CALS/EC (Continuous Acquisition and Lifecycle Support/ Electronic Commerce) standard. The main contents include network release of project information, electronic bidding, electronic signing, electronic submission of design and construction information, and reuse of process information in the use and maintenance stage, the application of the performance database of the projectB8.

f. BIM in China (including Hong Kong) started relatively late, but developed rapidly. From 1998 to 2000, there were some construction accidents caused by non-standard, which caused public concern about building quality. Taking this opportunity, the application of BIM and information technology in Hong Kong construction industry has gradually developed (B8).

   The 2001 CIRC report revealed that IT can help improve the efficiency of the construction industry by changing the behavior of the engineering participants (B8), enhancing the design ability and strengthening the information flow of the engineering logistics, and recommends that the construction industry should give priority to the establishment of general standards and study the common data base so as to facilitate the seamless communication of electronic data.

In June 2002, Hong Kong environmental transport and Engineering Bureau issued an advisory report on the environmental sustainability design ESD (Environmentally Sustainable Design), which aims to provide services for the communication and information sharing of different participants electronically in the implementation phase of the project (B8). In 2005, the Hong Kong environmental transport and Engineering Bureau arranged the implementation steps of the standards for public engineering data, including a series of implementation steps, such as funds, basic equipment, public engineering data standards, supporting software, and service platform software, WPCP, which were produced in accordance with the standards of public engineering data. In 2006, the Housing Department of Hong Kong developed HOMES, an enterprise's internal management system, and then applied BIM technology in 2009 (B8). As the time pass by, there are some specification issued by the government, such as BIM Project Specification (HK Institute of Building Information Modelling, revision3.0, June 2011), CIC Building Information Modelling Standards (HK Construction Industry Council, September 2015） , Building Information Modelling for Asset Management (BIM-AM) Standards and Guidelines (Electrical and Mechanical Services Department, November 2017), and so on.

The application of BIM technology in China has been developing rapidly in 2016. Influenced by the overall demand of the reform and development of the developed countries and the construction industry, BIM technology is gradually popularized in the field of construction engineering (B8). Most of the provincial governments have also introduced relevant BIM policies. Some provinces have already started the marketing and popularization of BIM technology under the promotion of the government, association and enterprises. The above contents are shown in Table 2 below.

Region	Organization	General Objective
--	Ministry of Housing and Urban-Rural Development	Improve the informatization level of the construction industry in an all-round way, and strive to enhance the BIM and other information technology integration and application capabilities to reach the international advanced level of construction enterprises and construction information technology enterprises with key independent intellectual property rights
Tian Jin	Urban-rural Construction Committee	Promotion the BIM technology in Tianjin
Jiangsu Province	Government	Promote scientific urban planning, orderly construction, intensive development, efficient operation and fine management, and strive to build a modern city full of vitality, beautiful and livable environment, distinctive culture and social harmony and civilization
Zhejiang Province	Department of Housing and Urban-Rural Development	For guiding and standardizing the application of building information modelling technology in construction projects, promoting the development of information technology in construction projects, the quality and safety assurance, and improving the return on investment
Shandong Province	Department of Housing and Urban-Rural Development	Establish the policies and standard system to match the requirements of BIM technology., and the application for lifecylcle mangement of project based on BIM Technology by the end of 2017
Hu'nan Province	Department of Housing and Urban-Rural Development	BIM technology will be fully applied in projects, and BIM technology will be popularized in planning, investigation, design, supervision, construction, general contractor of projects, real estate development and other enterprises by the end of 2020
Shanghai	Urban-rural Construction Committee	Improving the application policy and market environment of BIM technology, enhancing the ability and level of employee enterprises and personnel to apply BIM technology in project, and becoming a leader and world-class BIM technology comprehensive application demonstration city in China

Tab.2 – BIM policies in China (Source: adapted from http://www.mohurd.gov.cn/)

2.4 Current situation of BIM applications

2.4.1 Visualization

Visualization is the form of "what you see". A model can show the scheme design. And it can also demonstrate the reality which will be constructed in the site. For the construction industry, the application of visualization in the AEC (Architecture, Engineering, and Construction) industry is widely recognized and used. This includes on the basis that the information of each component is expressed on the drawings with lines and other visualization tools. But the reality of construction requires the participants' imagination and their experience in mind. For the simple form of the building, people can easily image. But in recent years, the architectural

forms of the building are complex. Therefore, BIM provides a visual idea to make the information in front of people.

Jupp has compared the traditional method with 4D BIM for schedule management [21]. Similarly, Rolfsen explores how 4D BIM, as a new method of visualization, compares to other pre-existing forms of visualization like bar- and flowline-charts [22]. His research points out that four-dimensional BIM was acknowledged as a powerful visualization tool. And it was at the same time perceived as difficult to use because of the practitioners cannot be succeed in increasing their IT capabilities. Therefore, in this paper, we will try to revise the traditional project management workflow and formulate corresponding BIM application requirements, so that participants can understand the standards and methods of BIM application, so as to improve the quality and efficiency of project management.

2.4.2 Coordination

This aspect is the key content in AEC industry, including all of the stakeholders such as the owners, the contractors, the consultants and so on. In this regard, the project manager should coordinate the relevant participants to solve the conflict. The BIM application can help deal with this problem as a information-tool for coordination between multiple stakeholders. Therefore, BIM can coordinate the major collision problems at the early stage and create the coordinated data on those given basis. However, the role of BIM is not only a solution to the collision problem between the various contractor, but also can solve the design problems such as the coordination of the fire zone and other design arrangements, the underground drainage arrangement and the other design layout.

2.4.3 Simulation

The anticipation of project progress is not the only application of BIM simulation. In all of the perspective of the project management, the simulation can be used to the lifecycle of the project. In the period of concept design, BIM can help to conduct a set of building simulation and

assessments, including the environment and landscaping, and the building form simulation. This can help the design team members and project owners to make the decision of the development. Jupp explores how environmental planning and management can be support by 4D capabilities [21]. She points out that effective environmental planning and management presents a range of process and informational challenges to project participants. The facets, included communications, information flows, difficulties in identifying and monitoring interdependences between environmental management plans and so on, are the gaps. She also establishes the 4D BIM workflow to support environmental planning and management. This research will make a specification for identifying the standard of application of 4D BIM for the view of the client in the initial stage of construction.

When the concept design has been confirmed, the construction drawing for the detail of construction would be simulation for the consultant of quantity surveyor (QS), whom can provide a clearer and more comprehensive overview for the unit of rate in the tender documents. The more detail is revealed in the tender document, the less claim will happen in the construction period. Therefore, in the construction stage, 4D simulation (3D model plus project schedule) can be carried out based on the construction organization, design and simulate the actual construction situation, so that the reasonable construction progress can advise the project management. In Peru, Murguia [23] held a workshop to assess the improvement in understanding of the construction flow when 4D models are used with undergraduate students. In this statistical analysis, students improved their understanding of the construction flow significantly by using 4D models, achieving results superior to those afforded by traditional tools, such as drawings or spreadsheet schedules [24]. Therefore, from this study, we can imagine that the site construction workers will have a more intuitive understanding of the construction process and requirements through 4D BIM application, and will have a significant improvement in the quality and efficiency of project management.

On the other hand, in recent years there are some 5D BIM application cases. SOHO China has done some testing in Bund SOHO project (situated in Shanghai, China). All the project team work together to share information, and increase the cost because of information communication is not timely, repetitive, errors brought about by rework and other losses, so as to enhance the project's production efficiency, improve the quality of construction projects, shorten the construction period, reduce construction costs, to promote the quality and efficiency of work improved significantly. [25] In Chapter 4, this will be discussed more thoroughly on the common data environment (CDE) to match the requirements of all participants in the same data environment for information exchange and application, and to avoid erroneous decision-making in project management due to gaps in communication and information transmission.

2.4.4 Optimization

In each stage of the project, BIM application can optimize the design and the construction processing of the construction through the visualization and simulation. In the same case with SOHO China, the design has been revised according to the clash detection. According to the visualization modelling and the information of the price in each element, the project manager can easily have the common sense of the cost controlling. Therefore, the project manager can also adjust the processing of the construction with efficient method so that the schedule can be under control.

In this research, the foremost objective will be focused on methods that are proposed to optimize the workflow of cost control, schedule supervision and quality control with BIM application.

2.4.5 Parameterization

The most important fraction of the BIM is the use and availability of information to multiple stakeholders of the project. From the practical

experience of the researcher, the experience of project management can be accumulated with the data of the BIM application. This means, the same type of the project can be arranged with the similar method. The basic data of the BIM can be classified in product family information. So we call it parameterization. The element of modelling can be parameterized so that the data base will be established and used more and more friendly. In this regard, the data can be accumulated for the company for further processing and application. Project manager would collect the information and analysis the standard of modelling. Thereafter, the company can establish the parameter resource database. When a new development project is set up, the database can help the high efficient collaboration in the process of the project management.

Consequently, in 2016, Housing construction department issued Outline of Development of Construction Industry Information (2016-2020) (W4). The document clearly pointed out that we should actively push the "Internet +", the transformation and upgrading of the construction industry, focusing on promoting BIM technology. In recent years, government departments have issued a number of BIM-related promotion policies, which include not only the policy requirements of BIM technology promotion, but also the project promotion objectives and technical guidance for the project lifecycle of BIM application.

2.5 Specific Guidance Issued by British Standards Institute (BSI)

The Publicly Available Specification (PAS) was sponsored by the Construction Industry Council and its development was facilitated by the British Standards Institute (BSI) Standards Limited and published under license from BSI (source: https://www.bsigroup.com/). This research attains some guidance and concept from BSI. The following sections highlight specific guidance issued by BSI.

2.5.1 PAS 1192-2 (2013) [B4]

《Specification for information management for the capital/delivery phase of construction project using building information modelling》

(Hereinafter referred to as PAS1192-2) [B4]. The main content of the PAS1192-2 shows the conception of the anticipation of the BIM application. PAS1192-2 provides specific guidance for the information management requirements associated with projects delivered using BIM. And it describes the BIM maturity levels and requirements of information delivery.

a. BIM maturity levels

Figure 2 illustrates the main elements of the various stages of the BIM technology development process, as well as the expected of the BIM. From the earliest CAD two-dimensional drawings to reflect building information and the current stage of 3D model, it is a qualitative leap. After establishing the basic information data of BIM, the usage and exchange of information began to have a standard definition and requirements.

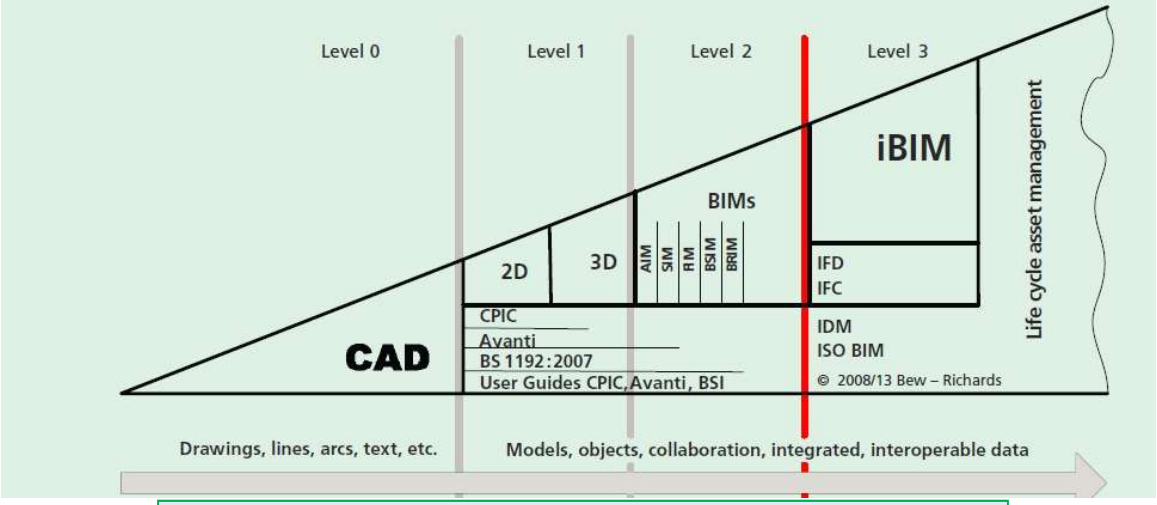


Fig. 2 – BIM maturity levels
Source: adapted from PAS 1192-2:2013, Page VII

b. The information delivery cycle

Figure 3 shows the information delivery and project management cycle. The BLUE cycle describes the generic process of identifying a project need, procuring and awarding a contract, mobilizing a supplier and generating production information and asset

information relevant to the need. This cycle is followed for every aspect of a project shown in GREEN.

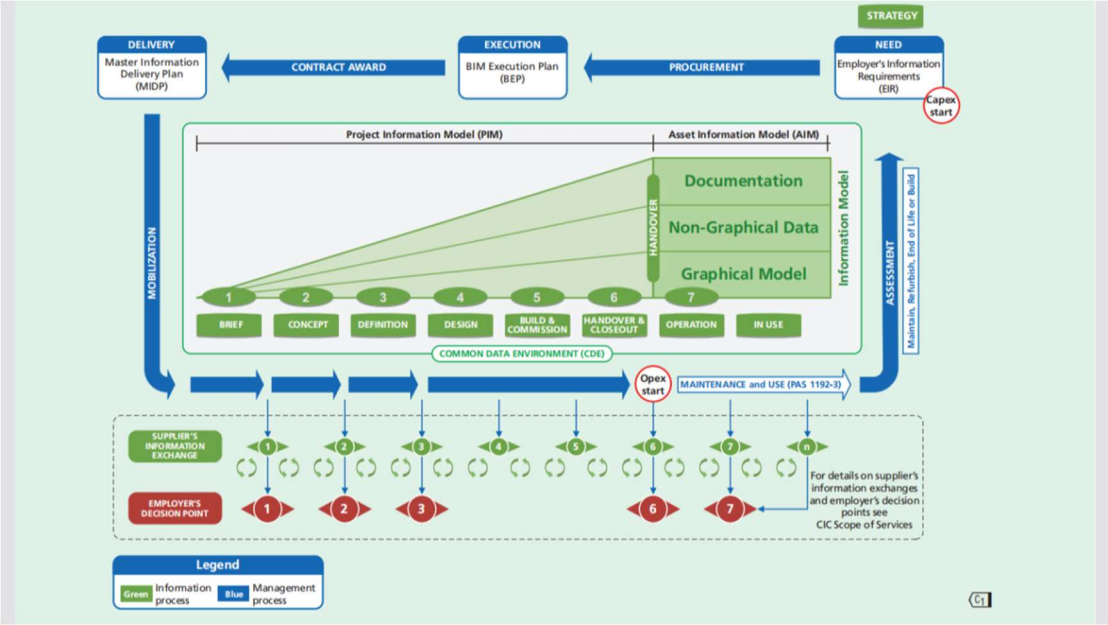


Fig.3 - Information delivery cycle
Source: adapted from PAS 1192-2:2013, Page VIII

c. *Fundamental principles of level 2 information modelling*

The specification explains the details of modelling system. There shall have provision of a clear definition of the EIR and key decision points. Employer should evaluate the proposed approach, capability and capacity of each supplier before the contract awarded. A BIM execution plan shall be developed by the contractor. All of the information should be stored and shared in one single environment. Therefore, the asset data and information need to be produced, used, and maintained in this system.

d. *Contents of the employer's information requirements (EIR)*

Some contents from PAS1192-2 for the research are shown as the followings. The target of specifications in Chapter 4 are brought out to be consistent with these requirements, levels of detail (e.g. requirements for information submissions at defined project stages). This is needed to populate the Model Production and Delivery Table

required under the protocol), training requirements, planning of work and data segregation (requirements for bidder's proposals for the management of the modelling process), Co-ordination and clash detection (requirements for bidders proposals for the management of the co-ordination process), collaboration process (requirements for bidders' proposals for management of the collaboration process), a schedule of any specific information to be either excluded or included from information models, a schedule of any software formats, including version numbers (that shall be used by the supply chain to deliver the project), exchange of information (alignment of information exchanges, work stages, purpose and required formats), clients' strategic purposes.

e. Common data environment

Figure4 shows the extending common data environment (CDE). In Chapter 4, the requirements and workflow of CDE will be carried out for the research.

2.5.2 PAS 1192-3 (2014) [B5]

《Specification for information management for the operational phase of assets using building information modelling》(hereinafter referred to as PAS1192-3). PAS1192-3 is a companion document of PAS1192-2. The relationship between these two specifications can be seen from Figure 5.

2.5.3 PAS 1192-6 (2018)

《Specification for collaborative sharing and use of structured health and safety information using BIM》(hereinafter referred to as PAS1192-6). The safety management is one of the most important aspects. PAS1192-6 provides guidance on how H&S information is produced, slows and can be used throughout the project and asset lifecycle [B6].

Risk can be identified earlier using information models, and controlled better by using models. PAS1192-6 defines harm, hazard, risk, and so on. One of the key content of PAS1192-6 is health and safety information

management, which should be defined, used, shared and summarized within wider community. In the lifecycle of project management, all of the participants should share their experiences in the same CDE to improve health and safety management.

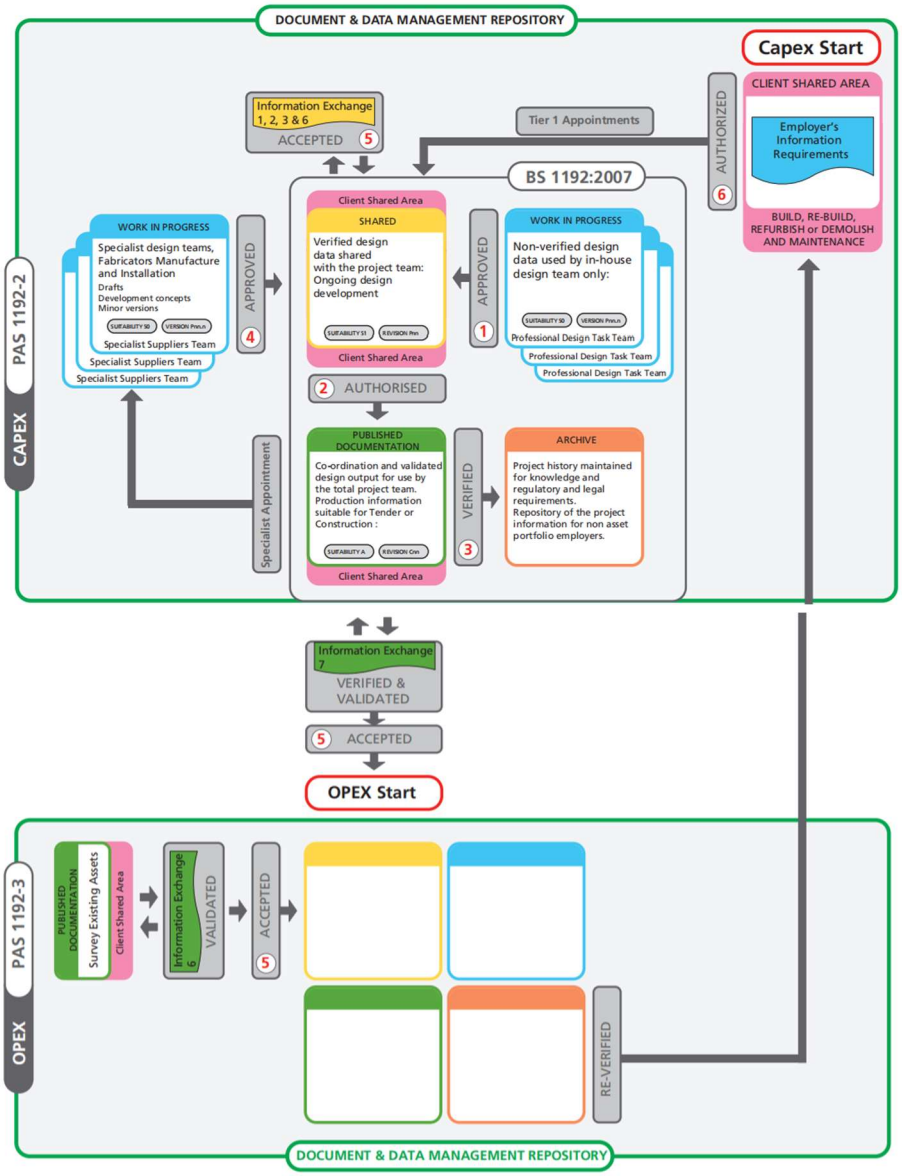


Fig.4 - CDE
Source: adapted from PAS 1192-2:2013, Page 26

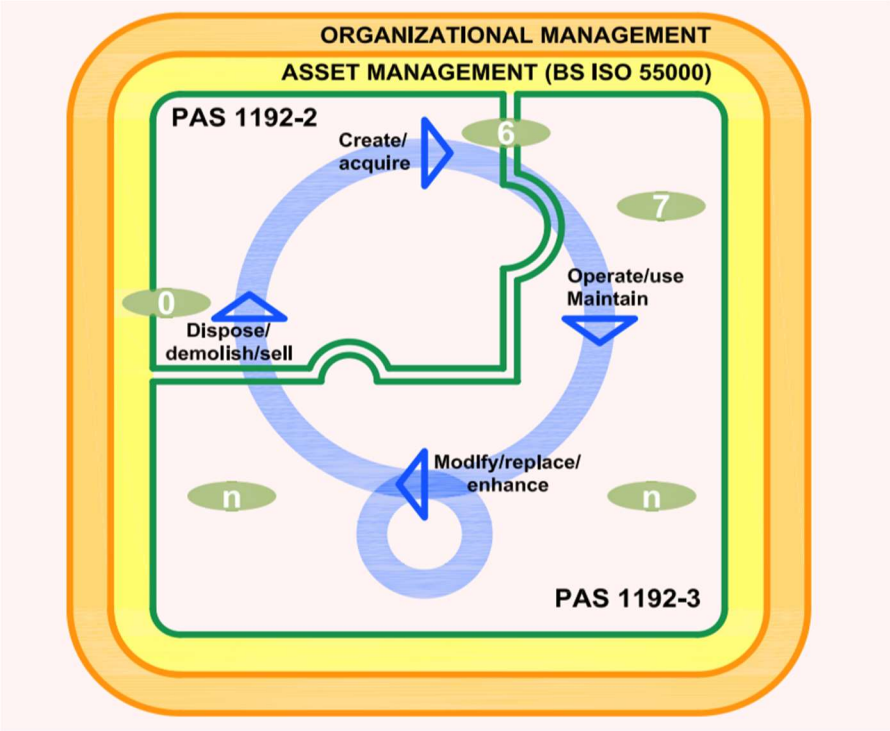


Fig.5- Relationship (source: Page VI, PAS 1192-3:2014)

2.5.4 ISO 19650 (2018)

《Organization and digitization of information about buildings and civil engineering works, including building information modelling(BIM)》(hereinafter referred to as ISO19650, W5) divides into two parts: Part1 Concepts and principles; Part2 Delivery phase of the assets. ISO19650 is applicable to the life cycle of building asset.

The specification focus on the information management process of asset delivery phase. First, the information receiver shall consider the information requirement, schedule of delivery and the standard of information among all of participants. At the same time, receiver shall establish the common data environment. Then receiver shall confirm the information requirement of asset, the implement plan and delivery plan. Collaborative production of information and information model delivery is the most important step for all of participants. After the project closeout, the executor shall evaluate the implementation effect of the whole process and capture lessons learned for future projects.

2.6 Guidance issued by MOHURD (China)

Influenced by the new technology innovation of the construction industry in developed countries, BIM technology has been rapidly developed and used in China's domestic construction field. First, Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) issued the 'Outline of Construction Information Development 2016-2020' (W4). In this document, it is clearly pointed out that the five major information technologies, including BIM technology, should be promoted. Subsequently, MOHURD issued another document, a standard of BIM application, hereinafter referred to as GBT51212, W4). GBT51212 identifies basic requirements of BIM, BIM model structure and extension, data interoperability and BIM applications.

After that, MOHURD issued 'Guidance on promoting the application of building information modelling'. The guidance illustrates the principle of BIM application for the project management. It also explains the role of the participants of projects and the key point of works. According to the investigation, the number

of projects which have used BIM technology reached the amount of 423 between 2015 and 2016 in Shanghai. And the Department of Urban-rural Construction Committee of Shanghai had published a series specification for BIM applications by the end of 2016. They include but not limited as the followings: "*Application standard of building information modelling*, *Technical standard for building information modelling of urban rail transit*, *Delivery standard for building information modelling of urban rail transit, Application standard for building information modelling of road and bridge".* (Source: http://zjw.sh.gov.cn/)

With the experience's accumulation of the application of BIM, the government of Shanghai continued to launch the guidance and training for the professional personnel. Figure 6 shows the number of project using BIM technology in 2016. Figure 7 reveals the type of project using BIM technology.

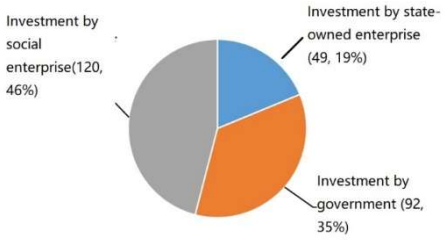


Fig.6- Type of project
Source: Architecture Science and Technology' (WeChat, 21st Sep, 2017)[W1]

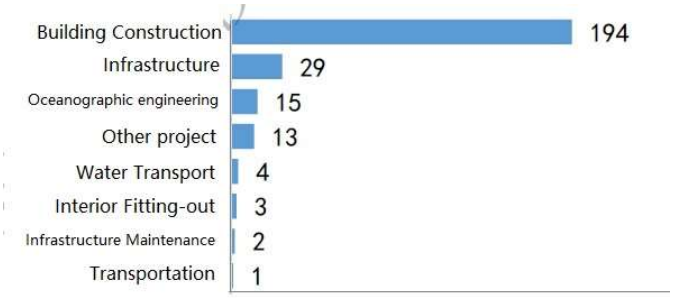


Fig.7- Type of project using BIM
Source: Architecture Science and Technology' (WeChat, 21st Sep, 2017) [W1]

Although the specifications in China have been issued by the government for several years, the requirements and the objectives of BIM applications cannot be described clearly for the participants. The details of modelling standards are still not nominated and appointed. On the contrary, the objectives and requirements are definitely described due to the standards published by BSI of UK. And the data environment is also clearly defined in those standards. After comparing the standards between China and UK, PAS shows more detail in specifications. But both of them are the guiding principles. The specifications must be a guidance to all participants and should be easily acceptable and implemented. So in this research, the creation of the specifications for BIM applications will refer to BSI

standard. And the Chinese policies will not be ignored.

2.7 Applications of BIM

Table 3 reveals the application contents of BIM in Shanghai. It is obvious that visualization and aided design are still the main application points at the contemporary. Factors, such as conflict detection, model building and virtual roaming are the dominant applications. Table 4 shows the application of software including the domestic and international productions in Shanghai. The above data excerpt from ‘Application and development report of building information modeling technology in Shanghai (2017)’. (Source: http://zjw.sh.gov.cn/)

Conflict detection and pipeline integration	65%
Setting up the modelling	65%
Plan/Elevation/Section inspection	61%
Virtual Roaming	56%
Shop drawing design	49%
Space optimization	46%
Quantities calculation	44%
Simulation of construction scheme	43%
Comparison of schedule	40%
Comparison of design scheme	37%
Quality and safety management	32%
Analysis of site	32%
Facilities management	27%
Completion modelling	19%
Operation system	6%
Asset management	5%

Tab.3- Applications of BIM in Shanghai
Source: Application and development report of building information modeling technology in Shanghai (2017)

Revit	83.9%	Project Wise	23.2%
Navisworks	67.9%	Civil 3D	23.2%
Tekla	46.4%	PKPM	21.4%

3DS Max	44.6%	Ecotect	17.9%
Autodesk 360	39.3%	Catia	17.9%
Sketchup	37.5%	Bently	12.5%
Luban（鲁班）	35.7%	Archibus	8.9%
Rhino	30.4%	iTwo	7.4%
Glodon（广联达）	28.6%	Vico	5.4%
ArchiCAD	25%	Micro Station	5.4%

Tab.4- Applications of software in Shanghai
Source: adapted from "Application and development report of building information modeling technology in Shanghai" (2017)

2.8 Investigation of Contemporary Practice

In Chinese AEC industry, many enterprises are actively trying to apply BIM, and some of them have achieved good results. This section will introduce the current BIM application in Chinese AEC industry from the perspective of developers and BIM application platform.

2.8.1 Example of 'Wanda Group'

'Wanda Group' is a commercial property holding and management company in the world. By the end of 2017, 235 Wanda Squares had opened with a property area of 31.51 million square meters and an annual passenger flow of 3.19 billion people. Wanda Group has begun to explore and research the application of BIM since 2014. And Wanda Business Planning Research Institute and University of Nottingham signed the BIM cooperative R&D strategic agreement on 18th August, 2017. Through resource sharing, the two sides intend to jointly promote BIM technology application, BIM standard establishment, BIM manpower certification and other international cooperation issues [W1].

2.8.2 Example of 'SOHO China'

Founded in 1995 by Chairman Pan Shiyi and CEO Zhang Xin, SOHO China focuses on developing and holding high-profile branded commercial properties in Beijing and Shanghai. The Company rolled out high-quality, innovative products in prime locations and translated the innovative designs into iconic real estate which possesses strong appeal to property

investors and the local businesses and customer bases [W2].

SOHO China began to use BIM for the construction from 2010. Many SOHO projects are designed by Zaha Hadid, such as the Galaxy SOHO in Beijing and the Sky SOHO in Shanghai. Zaha is famous for its curves. In the construction process, the conventional measurement and design methods have more difficulties for curved buildings, so the 3D modelling method had been adopted.

The author of this research study has previously participated the projects of SOHO in Shanghai. The role of author was the coordinator for BIM application. The main responsibility was to coordinate the application of BIM from the design point of view by the project participants under the agreed principles. At the same time, in the Bund SOHO project, the cooperation with Revolution Im Bauwesen (RIB) to carry out some application tests. At the beginning of the test, the work involved detailed communication with RIB to investigate the needs of various departments in the project management process, including design department, cost control department, PM department, etc. After the investigation of the requirements, cooperative research was carried out to achieve the requirements between the BIM consultant (RIB) and the quantity surveyor. In the subsequent work, through further investigation and understanding of the requirements the new software functions were developed.

In the requirement of calculating the building area, because the calculation method of the software does not match the Chinese specifications, the data calculated by the model during the test process is different from the actual area. The requirement has not been perfectly solved. The quantities measurement had been calculated by the software based on the modelling. The test is for the concrete of the basement.

2.8.3 Example pf 'BIM Building Data Technology Co., Ltd.'

It was established in 2011. The company is focused on the R&D, sales and life cycle BIM consulting services of construction software, the company

has successfully implemented more than 100 projects in the commercial fields, municipal bridges, rail transit, smart cities (parks).

Building data integration platform (BDIP) is one of the productions of this company. The platform has accumulated rich experience in the application of the modelling. The model can be light weight to facilitate quick browsing and application. The advantage is that you don't need professional modeling software to communicate and discuss the project by reading the model in the browser of the platform. At the same time, it can also meet the needs of roaming, and simulate walking in the modelling to help design and determine the rationality of space size, including the optimum use of various types of space. It can measure the size of the model conveniently and quickly. Design conflict and collision detection are also important functions of the platform, and design modifications can be made more efficiently by sharing this kind of information to all of the participants.

Through the application of knowledge, collaboration, project, schedule and other modules, the platform integrates the unified management of information in the project, the management of collaborative communication, and the management of project tasks on the platform.

2.9 Unified Modeling

In this research, the user case diagram and class diagram is shown as the followings:

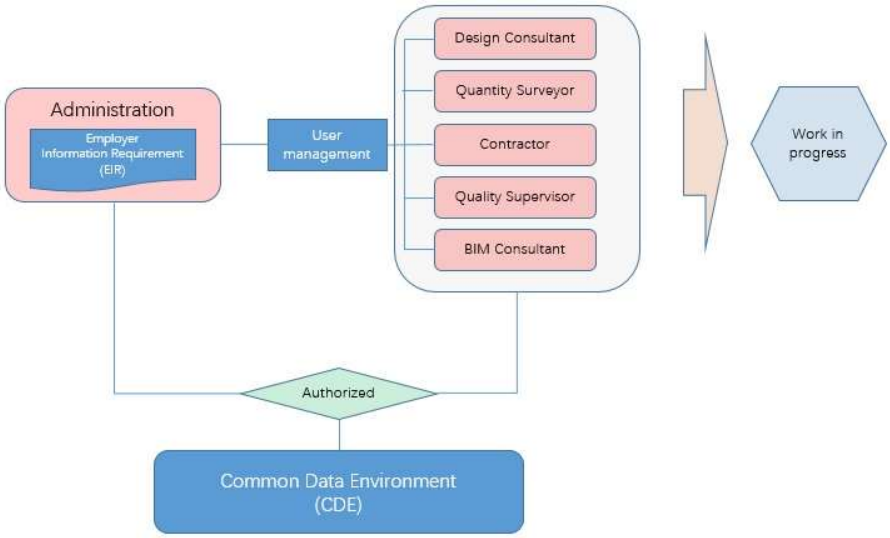


Fig.8- User case diagram (Source: Author's own)

Figure 8 illustrates the relationship between all of users in the project. The developer's team should be the administrator and focus on the access authority of participants. The information must be authorized by administrator and input into CDE.

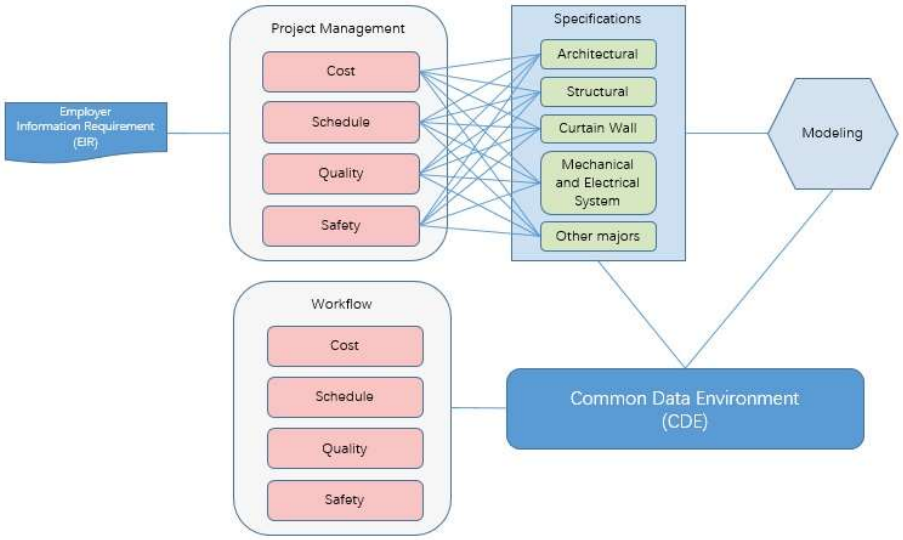


Fig.9- Class diagram (Source: Author's own)

The class diagram shows the contents of project management and specifications which would be established in this research. The information come out from CDE will be combined with the revised workflows.

2.10 Conclusions

Based on the study of traditional project management literature and the author's construction experience in China's construction market, the research and applications of BIM in Chinese construction market are investigated thoroughly in line to identifying the gaps in both research and practice. It is evident that the application of BIM in Chinese construction market is preliminarily understood. Nevertheless, s optimistic and positive attitudes towards the application of improving the level of project management in a green sign for the BIM application in practice.

Specification will guide the application of BIM, and project participants can gradually understand and accept these concepts, and use BIM as a tool to assist project management in design, construction and other aspects. According to the literature mentioned above, the researchers mainly focus on BIM applications, but have not established or explained the application specifications and requirements. At the same time, the research has not defined the depth of the model for different majors. On the other hand, the researchers do not integrate project management processes with BIM applications. Therefore, in order to optimize the workflow of project management, this study will combine the traditional project management workflow, according to the appropriate principle; establish BIM application specifications and the level of detail (LOD) for models.

Following the research of the literature and standards, the methodology of this dissertation will be introduced in Chapter 3. By researching and summarizing the traditional workflow of project management, the research will define the objectives and methods of BIM applications due to BSI standards, and optimize the workflows. According to advantage of BIM and combined with the applications, the client can improve the quality of project management, which is also the aim of this study.

Chapter 3 Methodology

3.1 Introduction

This chapter examines the methods taken to efficiently research the chosen research topic and how the whole of the report is going to be conducted from the beginning to completion. It is necessary to find out what is already known of BIM applications and a clear outline of why we are interested in undertaking the study on the revised workflow for the project management combined with BIM.

A detail description of the traditional method and workflow of project management was obtained at the start of the research. Whilst, we try to establish the specification of BIM applications based on the significant factors of project management. Then, according to the basic information collected and the previous research results, the traditional work flow of cost, schedule and quality in project management is revised in order to improve the quality of project management.

The research method is to analyze the traditional management process of mixed use commercial projects and find the useful applications of BIM. Then, according to the BIM specification, the reasonable and executable BIM application requirements are formulated, and the workflows of project management are optimized. In order to have a successful method for the research, it is helpful to make a flow chart that illustrates the step-by-step process for conducting the report.

3.2 Flow chart

Figure 10 demonstrates the methodology of this research.

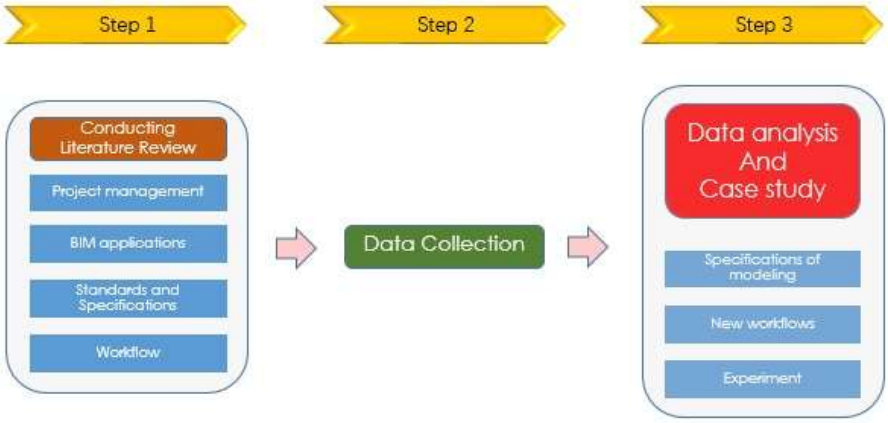


Fig.10- Methodology of research (Source: Author's own)

The proposed flow chart is divided into three parts: 1) Traditional workflow analysis, 2) specification of BIM applications, and 3) BIM+workflow for the project management (Figure 11)

Although the name of aspects in project management remain the same as traditional one, the contents of new workflow is optimized and illustrated in Chapter 4.

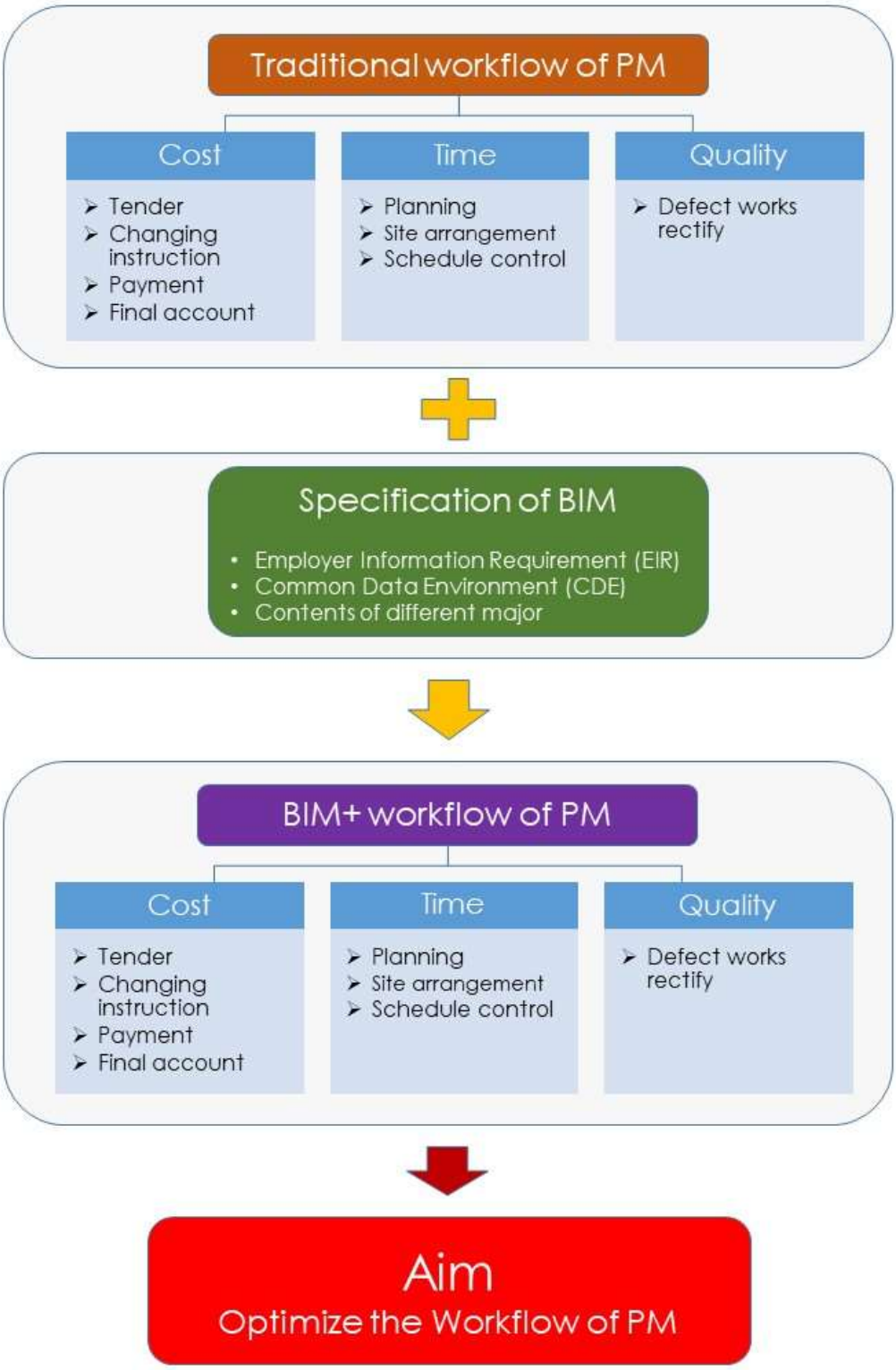


Fig.11- Flow chart of methodology (Source: Author's own)

3.3 Research methodology

This section will illustrate the method of conducting the study from start to finish.

3.3.1 Conducting literature review

To begin the research an extensive literature review needs to take place using journals, books, specifications issued by the governments and so on. This could be useful to understand the current BIM applications and the point views of developer in project management. The standards and specifications cannot be ignored at the same time. The review will provide a detailed analysis for key contents of project management and status of BIM applications.

3.3.2 Data collection

In this research, 4 types of data would be collected for the study:

a. Main applications of BIM in AEC industry.
b. Traditional workflow of project management in construction period.
c. Specifications issued by BSI; the elements of different majors in construction period for modeling.
d. The actual data of the case for testing the new workflow of project management.

The establishment of specifications is based on the investigation of BIM applications. The research could find out the limitations of traditional workflows and combine the BIM applications with the workflow. The testing of new workflow will illustrate the advantage of the research. At the same time, the limitation of new workflow will be found for the future research.

3.3.3 Data analysis and case study

According to the literature review and the questionnaire, BIM applications in construction stage can be conducted. On the other hand, by analyzing the key points of project management, the research try to find out the main BIM applications for project management, which can be useful to enhance the quality of project management.In case study, the traditional workflow of project management in construction period would be introduced. It is also linked to the key points of PM(cost, schedule, quality,

safety). The research would reveals the concept of reducing cost, schedule controlling and so on.

The literature review will illustrates the specifications issued by different countries. The research will analyze the concept of BSI. At the same time, the contents of different major's elements for modeling can be carried out from the case. The BIM applications will be introduced with the traditional workflow after the analysis. The aim of this research will be carried out in Chapter4. The new workflow of project management, combined with the BIM applications, would be created for the key performance in project management. The testing will be illustrated in case study. A tender processing of general contractor for the preservation project will use the new workflow. The research will analyze the result of the new workflow in enhancing the quality of tender procedure. Advantage and limitation of this research would be analyzed after the case study: finding out the advantages of the new workflow for application in project management, trying to think about the solution as the objectives of the future research through the limitations.

3.3.4 Research techniques

The research techniques of this study are developed based on the provided generic training and requirements of the project research. Figure 12 shows the main techniques in this research.

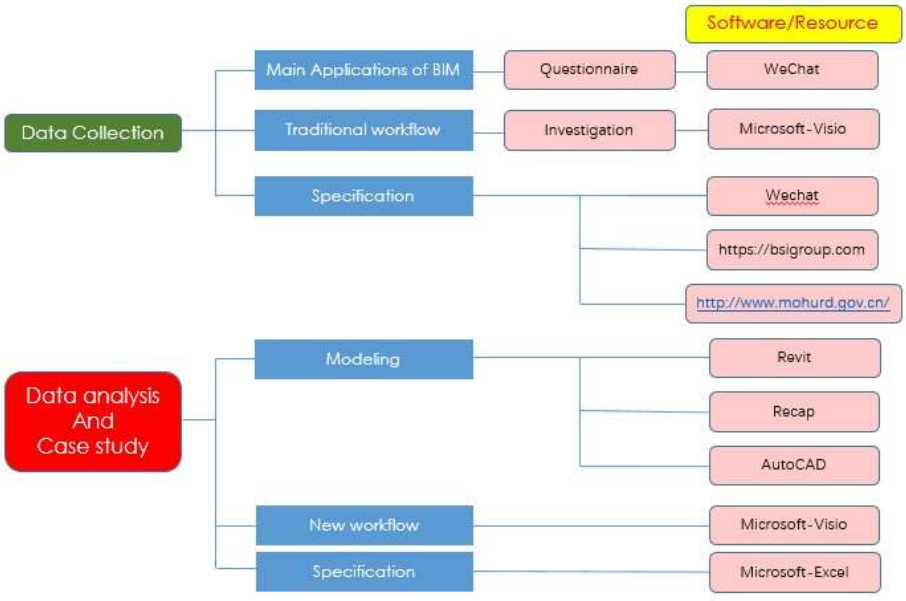


Fig.12- Technique (Source: Author's own)

At first, the study utilises information obtained from the literature in the initial stage of this research. It usually get the information from website such as Scopus, JSTOR, ProQuest and so on.

A questionnaire was created in WeChat APP (a widely-used social media platform in China) for collecting the BIM applications in middle 2018 in Shanghai, China. Some interviews between researcher and the interviewees are also based on this software.

The software Visio (2016) helps the workflow presentation. The modeling was made by Revit, Recap, AutoCAD.

The traditional workflow of project management is conducted by the working experience of the researcher, which is supported by in-depth assessment of the case study research.

3.3.5 The traditional workflow of PM

As discussed in Chapter 2, the significant facets of project management include cost, time, quality and safety. Pursuing profit is one of the important objectives of developers. The cost and timetable are the core components and the quality and safety cannot be ignored.

The detail of these four factors will be intensive studied in Chapter 4. The matching workflow will be summarized and discussed according to a completed mix-used commercial project.

3.3.6 Specification of BIM

According to combing the BSI specifications and Chinese local ones, three practice manual will be formulated in Chapter 4 as following gist.

a. Employer's Information Requirement (EIR)

In this research, the EIR will be identified according to the research of BIM applications and the requirements of project management. At present, some applications are still in the experimental stage, such as the measurement of quantity based on FIDCI mode. Because of the quality of the model cannot match the automatic measurement, so the requirements should be identified more reasonably.

b. Common Data Environment (CDE)

It is obvious that all project stakeholders must communicate based on the same information, whichever the information is. So that the discussion and decision would be efficient and timely. BIM applications, especially models, should be based on a unified data environment in which participants can obtain the same information in time, even if the information of the project is changing with the progress of the project. Therefore, appropriate workflow and uniform data environment requirements are more important. This research will follow this principle and try to create basic requirements and workflow.

c. Contents of BIM specifications for main majors

Many researchers realize that the specification of models needs to be defined at the initial stage of application, in order to facilitate the participants to understand the application standards and requirements. Manuele Cassano has describe the LOD standardization for construction site elements. [26] The research reveals that the development of a construction site information model during the different phases of a building project expressed the need to model also construction elements in different levels of detail according to the phase in which the model is used. In the research, it will illustrate the specification with scope of work, deliverables, quality assurance and quality control for model, hardware and software requirements.

3.3.7 Revised workflow with BIM applications

Some researchers give the detail about the workflow of BIM application. Julie Jupp illustrates the workflow of 4D BIM to support environmental planning and management. [21] Fig 13 shows 8 steps for the workflow: develop the model, study the budget of construction, develop the 4D model, research the critical path of construction, clash detection, represent the environment impact, 4D simulate and identify the unforeseen impacts of construction, monitor on site.

We can find out that the workflow of PM was ignored in Jupp's research. As introduced in section 3.1, we will combine the traditional workflow conducting in Chapter 4 with the specifications illustrates above. This is also one of the objectives in this research.

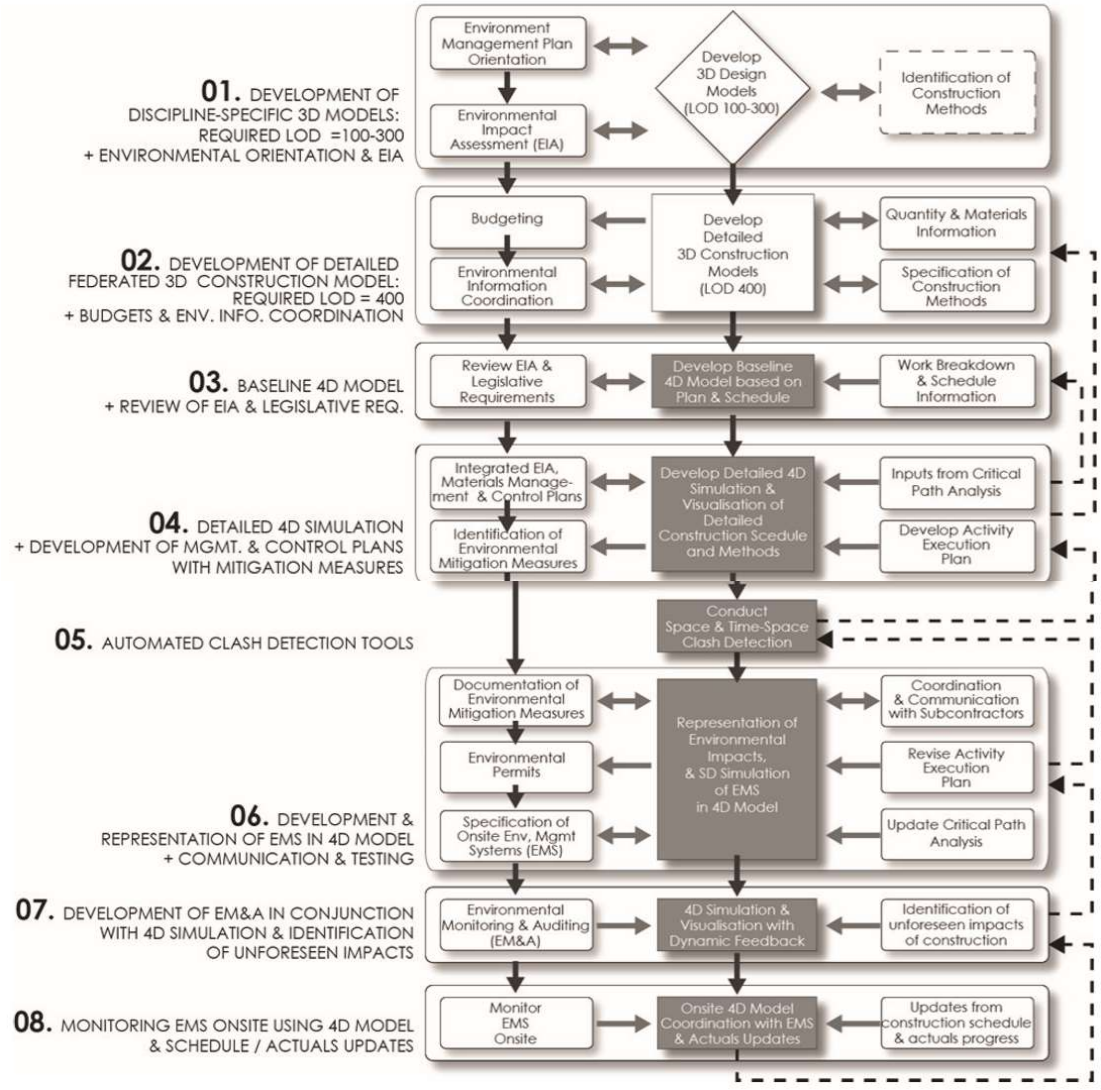


Fig.13- 4D BIM workflow (Source: [21])

3.3.8 Information collection

To obtain the necessary information, a questionnaire consisting of 2 parts was prepared. In the first part, the role of participants in construction was asked, as well as the years of service. And the second part is to understand the interviewee's views on BIM application. Finally, this questionnaire was administered face to face to 5 project participants employed. According this questionnaire, the research will understand the best combination

point of BIM application and traditional project management workflow.

The five people covered the employer, the construction contractor and design consultant. All of them have over 10 years working experience in architecture, engineering and construction industry. Both of them know the specification of BIM issued by China government. But all of them know nothing about the BSI standard of BIM.

In terms of BIM applications, five people mentioned design optimization, construction scheme optimization, construction simulation and cost optimization. One person mentioned facilities management. Two people mentioned the simulation of the site layout.

The designer focus on the application of design, such as the conflicts of drawings error. The client pay his attention in schedule control. So the 4D simulation cannot be ignored. However, the contractor pays more attention to the cost optimization brought by BIM application, and believes that construction simulation can help all participants understand the whole picture of the construction.

3.3.9 Practical experiment

The new workflow will be used in the new mix-used commercial project for tender process. The actually efficiency of this application will be analyzed in Chapter 4. However, the new project is still in the initial implementation stage, other new workflows will be gradually verified in future research.

3.4 Summary

This chapter demonstrates the methodology of this research project. It is formed according to the following process. It summarizes several important workflows of project management through the case study, including the key points of cost management, the method of schedule control, and the way of quality management. Then the problems of workflows will be analyzed according to the additional cost and the time delay. At the same time, learning BSI's specifications of BIM application and establishing a suitable standard system will be the significant processing for the next step. So that the workflows can be combined with BIM application for improving the quality of project management.

According to the research, some limitations were found as the following aspects:

a. Modeling making usually takes a long period. For example, it should take about 2 month for the structure modeling for a 40000m2 basement in Shanghai (Source: Author's own).
b. The results of automatic measurement will be affected by the accuracy of the model. In an office building project in Shanghai, when carrying out automatic measurement testing, it was found that according to the traditional measurement method, the concrete quantity of basement was 67080m3 calculated by quantity surveyor consultant. However, the result was 54459m3 calculated automatically according to the modeling. It was found that the model has some mistake (Source: Author's own).
c. Model revision during construction period cannot catch up the requirement of project progressing.
d. It should take a long time for training the ability of using BIM applications for all of the participants in the project.

How to solve these problems will be one of the next research objectives. First, we will improve the workflows of project management.

In Chapter 4, the traditional workflows will be introduced and the specifications of BIM applications will be created for the new workflows, which will be used in the new mix-used commercial project of next research.

Chapter 4 Case Study

4.1 Introduction

In this chapter, the overall structure of traditional project workflows will be illustrated at first. Afterwards, the information of the case will be introduced. The specifications of BIM applications would be set up as discussed in sub-section3.3.2. In this regard, the correspondence of revised workflow will be combined with the BIM applications based on the specifications. The new workflows are expected to be used in the new project, which includes tracking the result and obtaining the data for improvement of project management factors. These are taken into considerations as the main objective of the research

4.2 Traditional workflow of PM

Pursuing profit is one of the important objectives of developers. Therefore, cost and time are the core components of project management. On the other hand, the quality and safety of the project affect the sales and using experience of the product, and it is also the important factor of project management. Coordinating all of the participants and integrating to match the objective setting in the aspect of cost, schedule, quality and safety, should be considered as a very significant aspect of the owner's project management.

4.2.1 Cost

According to the process of project, the following aspects will be focused on the cost situation for cost controlling.

a. Estimate.

Investment budget is usually preliminary estimated according to the financial expected income before obtaining the land. It is a professional assessment of comprehensive evaluation based on the indicators by the conceptual design of the project and the cost data of similar projects, taking into account regional differences, time differences, etc.

After the concept design, the cost of the project will be updated according to more details of drawings. The quantities of the elements should be calculated artificially. The professional fields of quantity

surveying, cost controlling and contract management have developed a range of professional standards for many years. We can find out the introduction from Peter Smith's research. Standard Method of Measurement (SMM) of building works was prepared by the Royal Institution of Chartered Surveyors (RICS) in the United Kingdom. And now it is widely used in the whole world. So in this research, all cost information will be based on this calculation rule. And at the same time, the unit price is analyzed on the basis of experience and market. Once the budget is confirmed at this period, it will be serve as the cost control target for subsequent management.

b. Bidding Strategy

According to the different depth of the drawings and the requirements of the schedule, it is necessary to arrange the bidding strategies of various sections, including the contract mode (such as, the lump sum, the provisional quantity, the provisional unit rate, etc.), and the demarcation table of the contract should be considered. All the information will affect the contract conditions.

The contract conditions are usually based on FIDIC or JCT. Some special contract conditions will be set up for both the client and the contractors to comply with, which must be applied with the unique circumstances of the project. And this will be helpful to the post-contract management, especially for the cost control.

The tender documents are usually included the following parts, notice of tender, letter of quotation, agreement (draft), contract conditions, tender drawings, specification, bills of quantity

Following the traditional project management, the tender process is generally shown as the following figure (Figure 14)

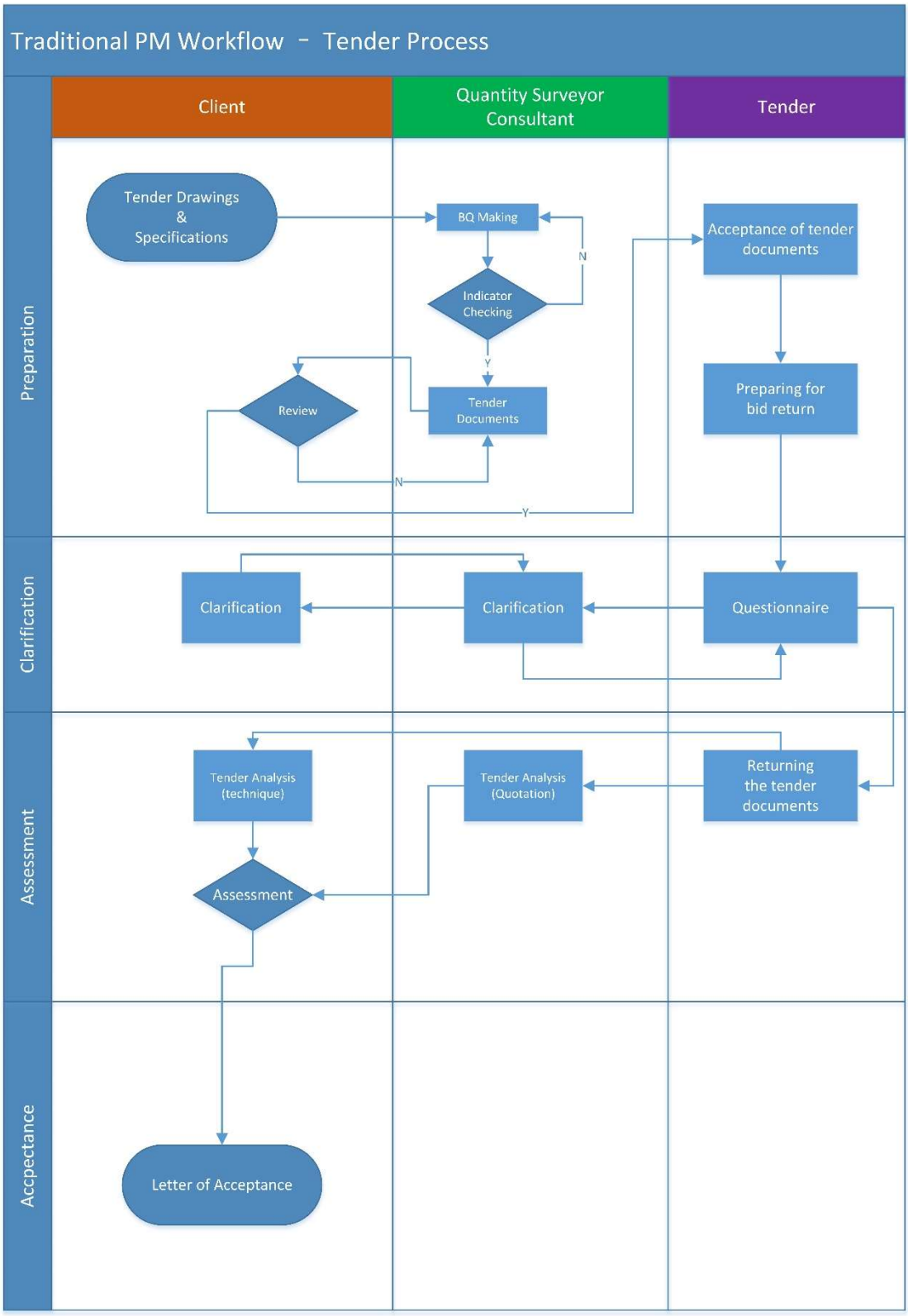


Fig.14 – Tender Process of Traditional Project Management (Source: Author's own)

This workflow often spends about three months for the main contractor tender process. One month is mainly used by the quantity surveyor

consultant, and the bill of quantities is compiled. Whilst, there is used to be lots of uncertain conditions which must be clarified because of the quality of the tender drawings. The clarification will take about a month.

One of the aims of this research is setting up a suitable specification for the tender modeling. It should illustrate the clearly demarcation table between each contractor. Moreover, it also can reveal the concept of design to all of the participants in tender period. At the same time, the workflow should be optimized, which is an important part of the overall project goal.

c. Changing instruction in post-contract management

In the construction period, cost control will depend on the assessment of the changing instruction, which precede the confirming the order. And it can be compared with the estimate. The main factors causing the increase of cost are found and intervened. This kind of work will be realized in the form of monthly financial report. Another factor that affects the cost is the fluctuation of the market price, including the labor, materials and machinery. For example, when the EXPO held at Shanghai in 2010, the construction of EXPO stadiums requires a large number of labors so that the price of labor in the market has increased significantly during this period. Therefore, it can be predicted that if the municipal authorities implement the social and economic infrastructure in a certain period and the price of labors and materials of the construction will increase.

The design modification during construction period is the main reason for the change. In the project introduced above, the variation of the design changing instruction occupied about 53.77% of the total variation. The main reasons for design changes include the following aspects, design mistaken, conflicts between drawings of different majors and unachievable of construction design detail. To provide an overview of these details, a detailed workflow for the changing

instruction is shown as Figure15 below.

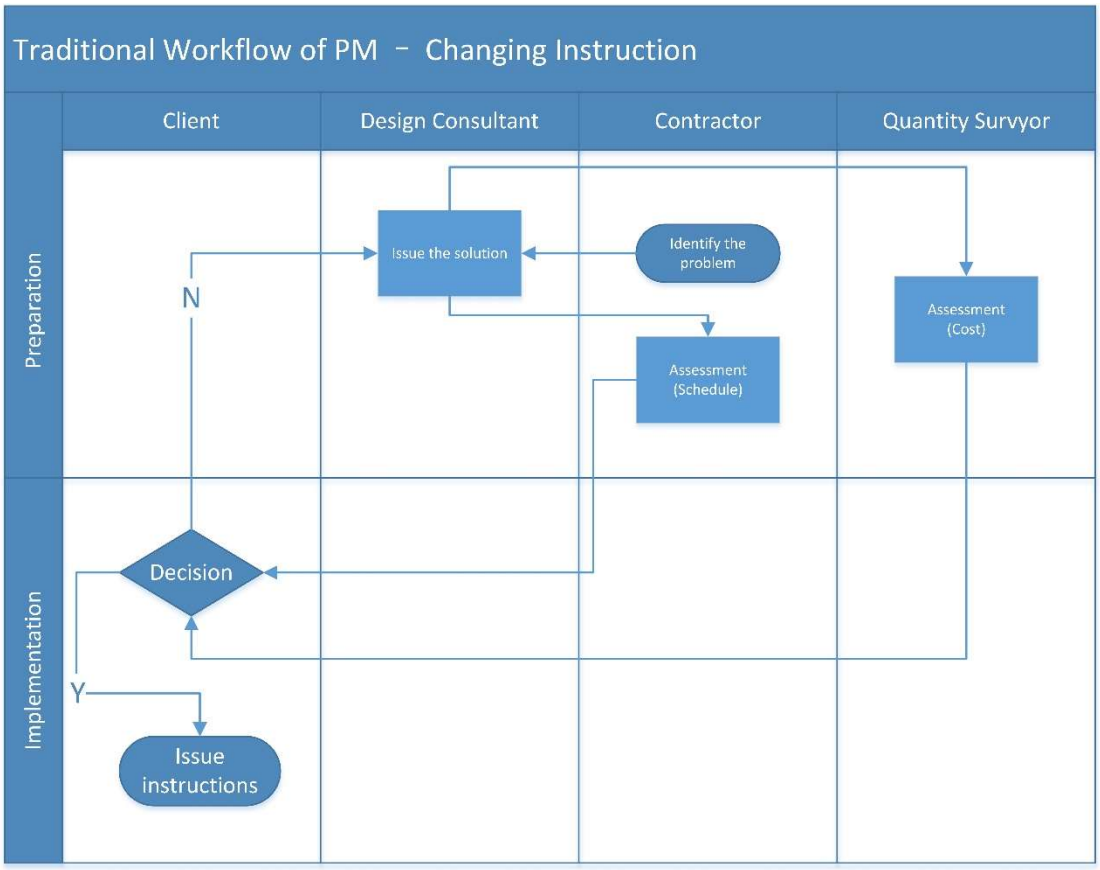


Fig.15 – Changing Instruction of Traditional Project Management
(Source: Author's own)

In this research, the specification and a new workflow for the design will be established for reducing the design mistakes. Therefore, the changing instruction workflow would be also revised and combined with the BIM application.

d. Payment

In the case, the terms of payment are stage style and signed in accordance with the requirements by the contract as shown in Table 5 below.

After the completion of the foundation slab of the basement	The payment shall be made to 70% of accumulated value of completed construction (excluded the retaining works)
After the completion of the construction of	The payment shall be made to 70% of accumulated

the basement	value of completed construction
After the completion of the construction of the podium	The payment shall be made to 70% of accumulated value of completed construction
After the completion of the construction of the office tower	The payment shall be made to 70% of accumulated value of completed construction
From the second month after the completion of the construction of the office tower	The payment shall be made to 80% of accumulated value of completed construction
After the license of completion issued by the government	The payment shall be made to 80% of accumulated value of completed construction
After the issuance of the completion certificate by the client and the submission of the completion documents by the contractor	The payment shall be made to 90% of accumulated value of completed construction
When the final account is accepted by both the client and the contractor	The payment shall be made to 95% of accumulated value of completed construction
After the validity period of maintenance	The payment shall be made to 100% of accumulated value of completed construction

Tab.5 – Payment (Source: Author's own)

In the traditional workflow, each payment procedure should be applied by the contractor first. The client and the supervisor must confirm the progress of the construction. Quantity surveyor will estimate the value of the completed construction and provide the payment proposal to the client. After receiving the payment proposal, the client will pay to the contractor in time. This workflow is illustrated as in Figure 16 below. This progress will take 28 calendar days for assessment and the research will insert the model control for the schedule confirmation and the quantity check. As a result, this can reduce the time of assessment for all participants in the project.

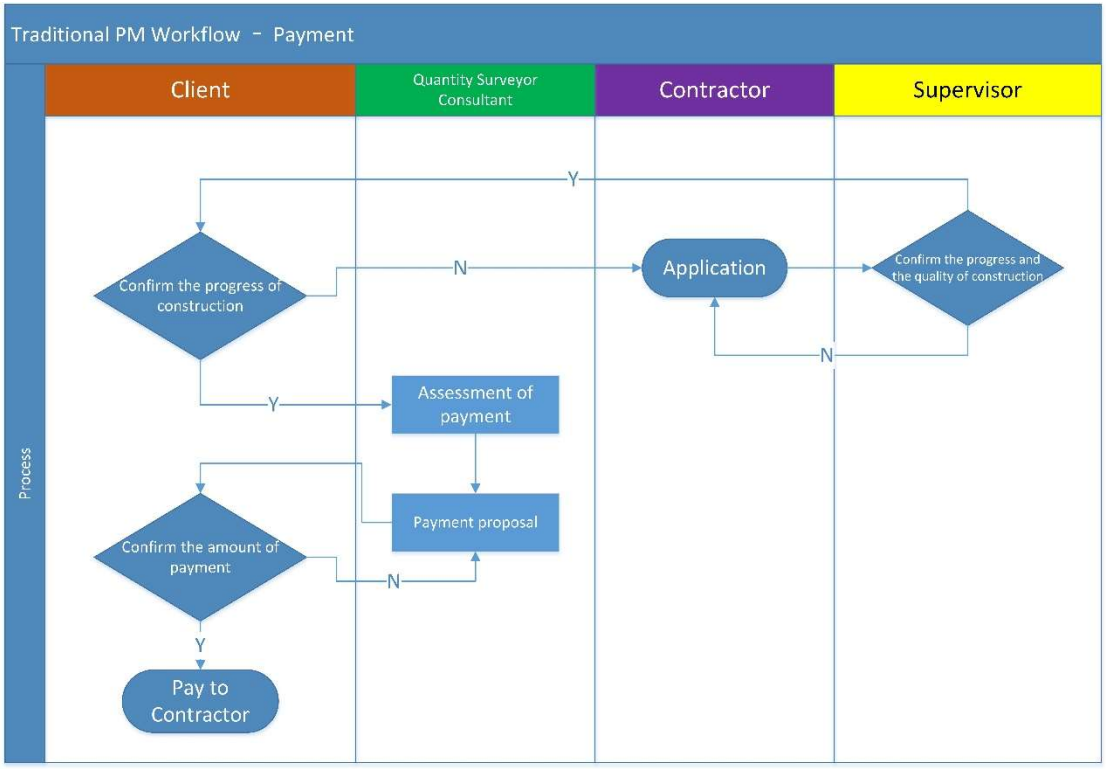


Fig.16 – Payment (Source: Author's own)

e. Final account

After completion of the project, the final account will be assessed by the quantity surveyor (QS). The contract (including the conditions of contract, the drawings, and the bills of quantities) will be the basis of final account. The instructions generated during the construction period should not be ignored. It will also be the evidence of final account.

In this project, due to the complexity of the construction process and several steps of design modifications, there are many claims for changing the instruction procedure. In the workflow of final account, the information needs to be sorted out, which is similar to the workflow of payment. The contractor needs to provide corresponding information when issuing the final account, which is confirmed by the client. In addition, the quantity surveyor would issue the assessment. The client and the contractor will negotiate with each other for these claims based on the assessment issued by the quantity surveyor. After

all claims have been agreed, the final account report will be issued by the quantity surveyor and it shall be signed and confirmed by both parties. Figure 17 shows the workflow of the final account.

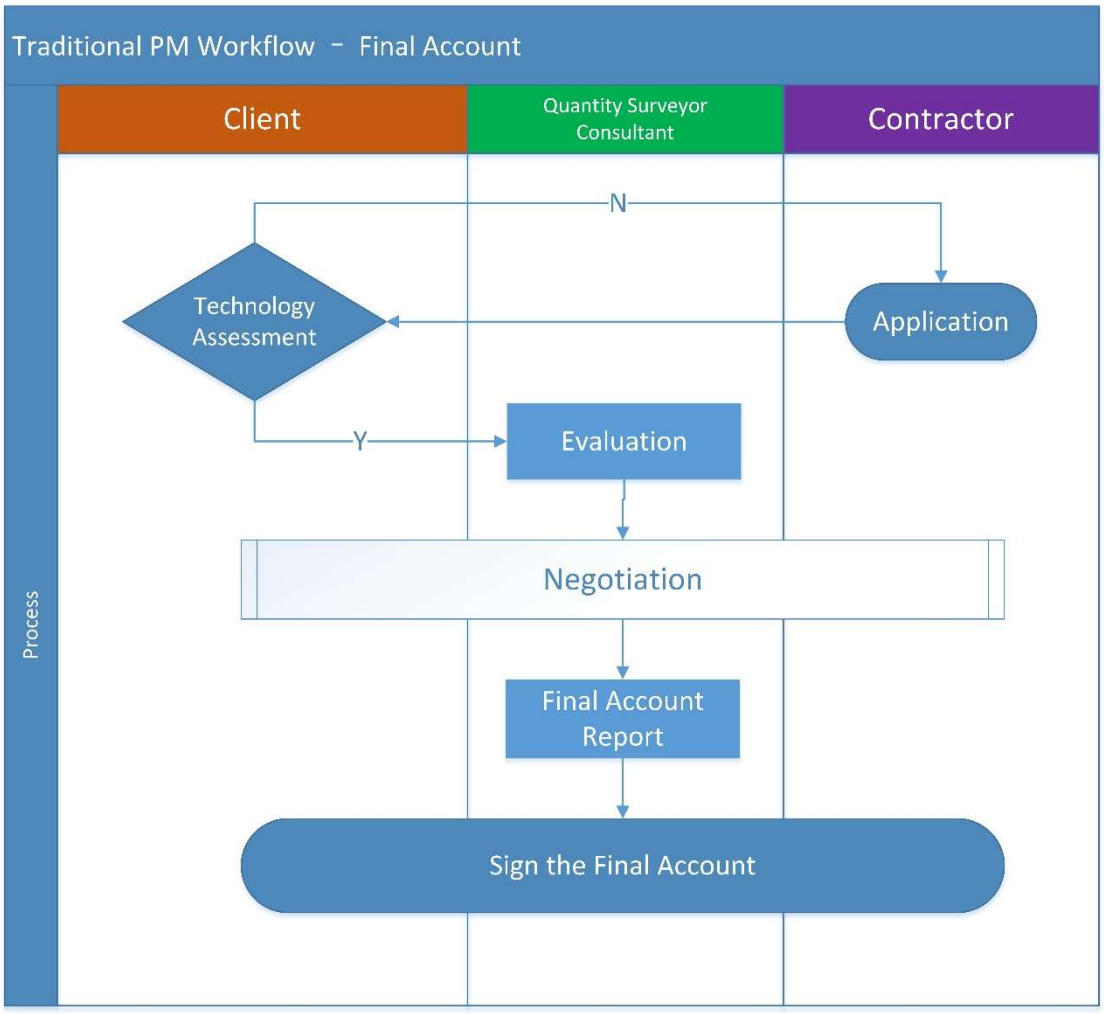


Fig.17 – Final account (Source: Author's own)

4.2.2 Schedule

a. Planning

The overall schedule of the project is confirmed at the commencement of the project, which is related to the development, construction, operation and return on investment of the project. The overall schedule of the project is described in sub-section 4.3.2.

In this research, the schedule focuses on the construction planning after the acceptance of main contractor. The target of the project

schedule needs to be achieved through rigorous management in the construction process. This reflects on the process of a typical traditional project management and associated tothe workflow of schedule management, which is shown in Figure 18 below.

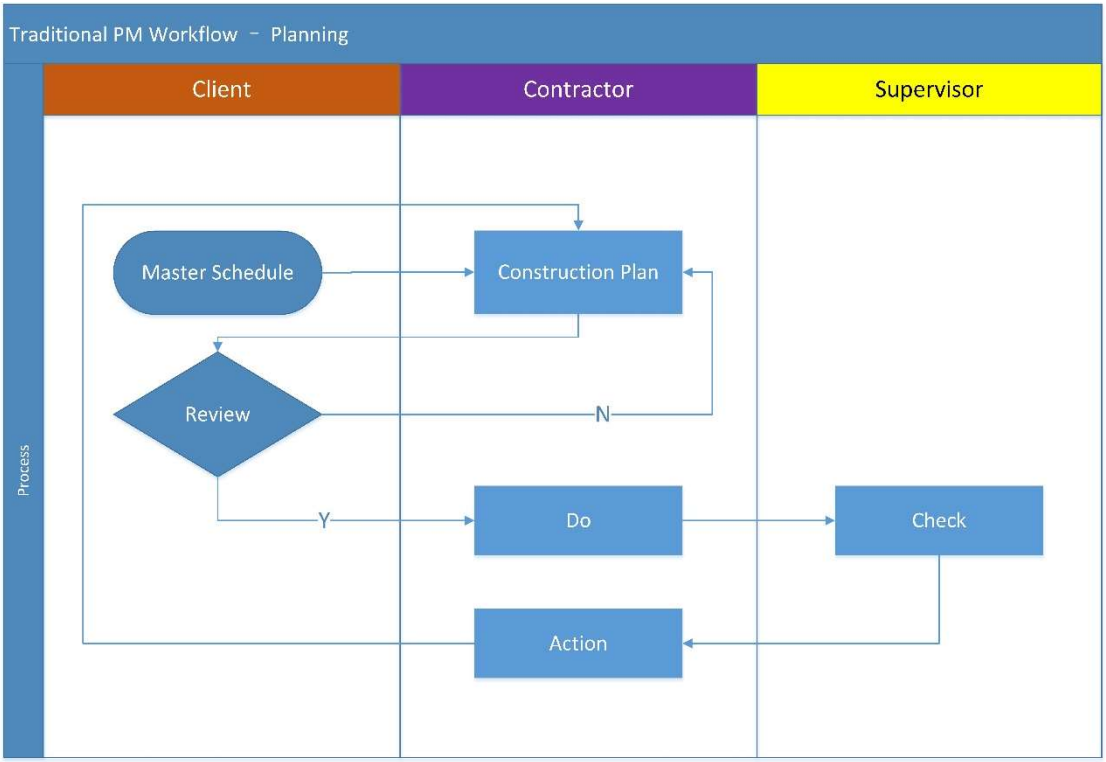


Fig.18 – Planning (Source: Author's own)

b. Site arrangement

In addition to the schedule, site arrangement, including temporary facilities, is also very important in the overall planning before the project commencement. It directly affects the schedule. In the traditional project management, the preliminary plan of site layout is put forward by the bidding unit during the bidding process. After the letter of acceptance is issued, the contractor will study the site in depth according to the site conditions. And according to the professional conditions required for the construction of the whole project, the construction equipment, such as tower crane, temporary freight elevator, and material processing sites will be reasonable arranged.

The workflow of confirmation for the site arrangement is usually

studied by the contractor in its own procedure. The client will not pay his attention to the situation and the detail of site administration. But the cost of those is also included in the contract amount and paid by the client.

The main contractor usually considers the site administration with his own requirements. So in the construction period, subcontractors are usually constrained by the conditions on the spit. Due to the shortage of material storage and making sites, the supply of materials is affected, causing the delays for the project.

By 4D simulation, the main contractor can arrange the site facilities by the progress of the project. The sub-contractor can also take part in the arrangement. The wastage of cost will be declined by the simulation of site administration in initial stage of construction. So this research will establish the new workflow about the site arrangement.

c. Schedule control

The schedule control is one of most important facets in construction management. After the milestone and the construction planning has been confirmed, the project team must follow the time and specify the detail schedule of each part. And all the participants should follow the flow of plan-do-check-action. The workflow is the same as Figure 14 shown. If there are delays in the work on key routes, it is necessary to analyze the reasons for the delays. At the same time, it is necessary to analyze the follow-up work and adjust it from the aspects of human resources, material preparation and equipment support, so as to reduce the delays as far as possible under the existing circumstances and the impact of the delays on the progress of the project.

4.2.3 Quality

Quality management includes many aspects, such as material quality,

processing quality, construction or installation quality. In traditional project management, it is necessary to set quality management objectives in the initial stage of the project to match the specifications and requirements of the local government. The information of requirements must be involved in the contract. The contractor will comply with these requirements in the subsequent construction process. According to the requirements, the supervisor inspects the contents of the completed working by the contractor. If there are unqualified parts, it needs to start the workflow of defect rectification. Figure 19 below illustrates the workflow.

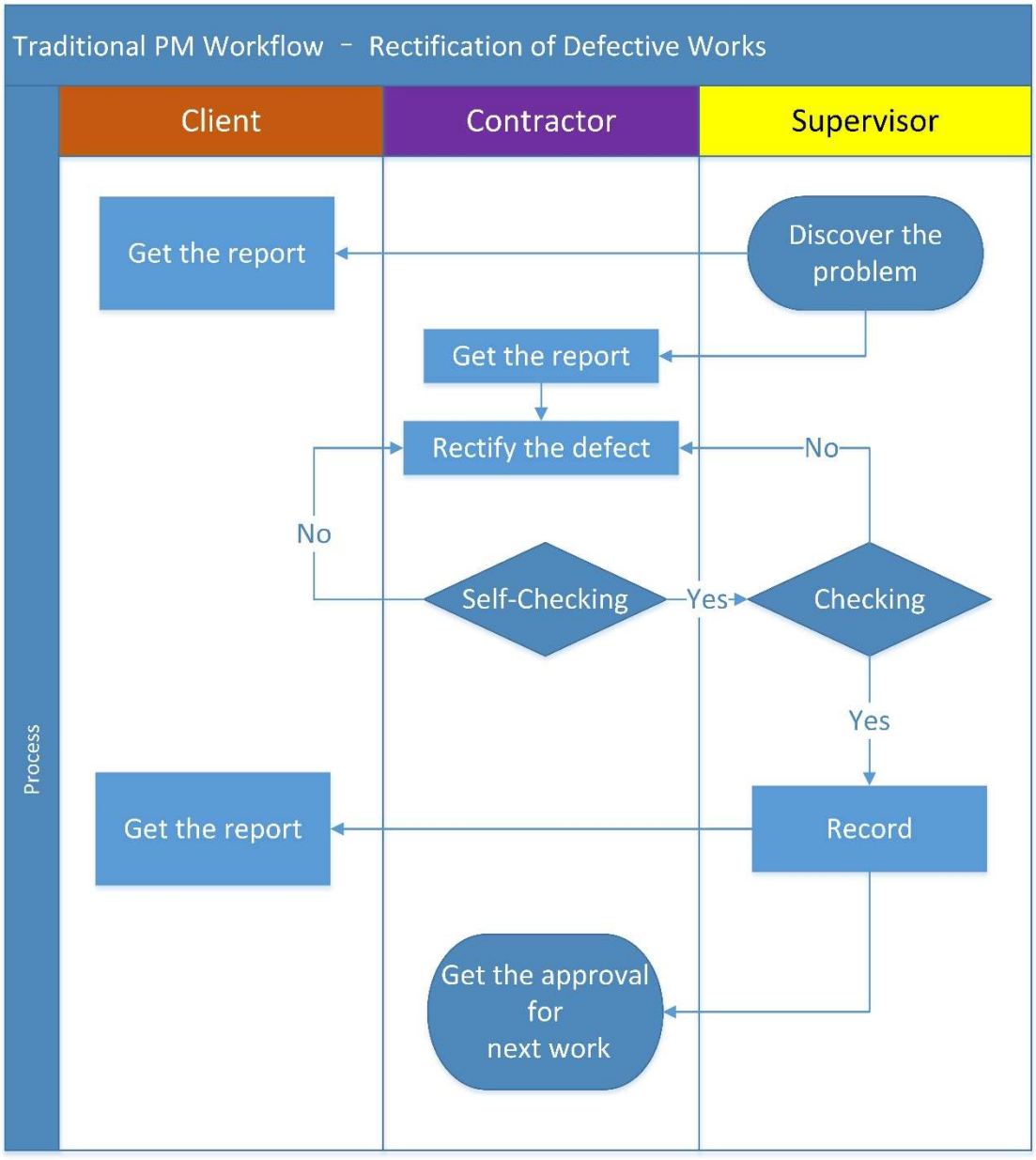


Fig.19 – Rectification of defective work
(Source: Author's own)

In traditional workflow, the supervisor makes the record of discovering the problem and rectifying the defective works. The information is usually communicated orally or in writing. Some defective works will be lost due to the communication method. The workflow will be adjusted with the BIM application and taken the advantage of the CDE for the coordination.

4.3 A brief introduction of the project

This a typical mix-used commercial project. It is situated at Yuhang District, Hangzhou, Zhejiang Province, China. Being the political, economic, cultural, financial and transportation center of Zhejiang Province, Hangzhou is an important transportation hub in southeast China. It is one of the central cities of the Yangtze Delta – the largest economic circle in China, and the permanent host city of the World Leisure Expo as well as China International Animation Festival. The location of the project is shown in Figure 20.

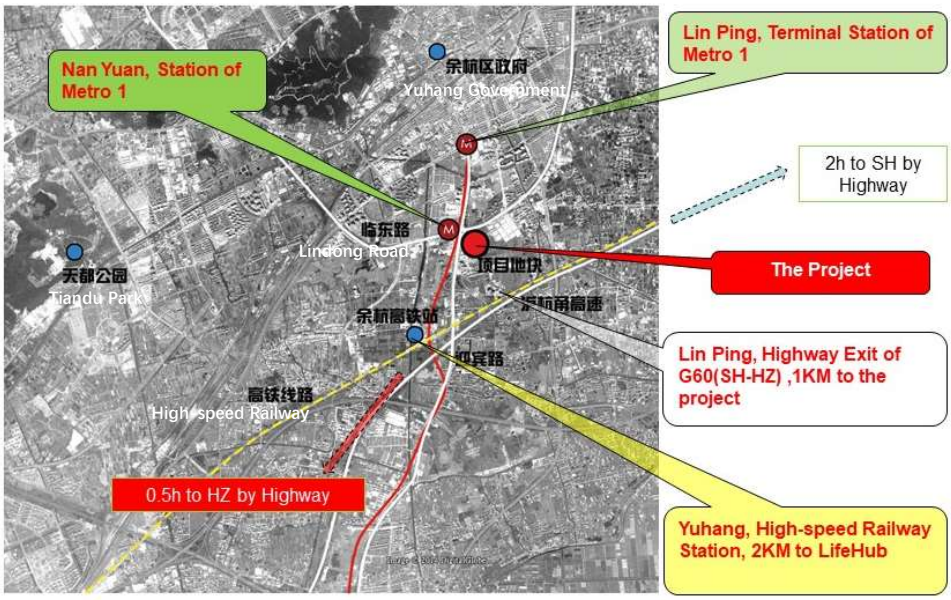


Fig. 20 – Location (Source: Author's own)

Based on the history of Yuhang District where the project is located, whilst considered with the environment, the architect presents the concept of the project with castle shape and the color of the pink porcelain of the Qing Dynasty (Figure 21)

Castle Colorful china @ Qing Dynasty

Fig. 21 - Concept (Source: Author's own)

The project includes 2 parts. One is commercial block with both three office towers and podium for retail, foodservice. Another is residential block with 8 towers. The master plan is shown as Figure 22.

Fig. 22 – Master Plan (Source: Author's own)

4.3.1 Budget

Estimation of projects refers to the costs during construction, excluding land costs, financial costs and management costs. According to the experience of similar projects and the location of projects, the estimates are divided into preliminary costs, construction fee (residential, commercial), public utilities levies (residential, commercial), consultant fee and cost of contingency as shown in Table 6 below.

Item	Cost(RMB)
Preliminary	51,700,000.00
Construction Fee for Residential Area	600,400,000.00
Construction Fee for Commercial Area	1,263,000,000.00
Public Utilities Levies for Residential Area	49,200,000.00
Public Utilities Levies for Commercial Area	127,600,000.00
Consultant Fee	112,500,000.00
Contingency	136,000,000.00
Total	**2,340,400,000.00**

Tab.6 - Budget (Source: Author's own)

Preliminary includes the cost of preparation for the construction, such as site leveling, temporary water and electricity connection for construction, etc. Construction fee includes the structure, architecture, electricity, heating/ventilation and air-condition, fire system, burglar alarm and security system, plumbing, drainage, accessory, etc. Public utilities are composed by water, electricity and gas. Consultant involves design consultant, quantity surveyor, supervisor, curtain wall consultant, M&E consultant and so on. Contingency fee includes unpredictable costs which is generally used for cost changes caused by abnormal fluctuations in material prices due to market factors, or for other unpredictable items outside the design scheme, usually calculated at 5% of the total cost.

In this research, we focus on the construction fee. This part of the content usually accounts for 80% of the total cost budget. All of the clients must pay attention to how to control the construction cost. In the traditional workflow, estimation, bidding, contract management and final account management are the important factors of the project management. And it will be discussed later.

4.3.2 Schedule

The project started in the end of 2014 and is scheduled to be completed in Q3 of 2017. In fact, there are many difficulties and emergencies in the construction period, which have a negative impact on the progress of the project. Based on the traditional project management method, the completion time of the project is delayed. The initial planning of the project is revealed as shown in Figure 23 below.

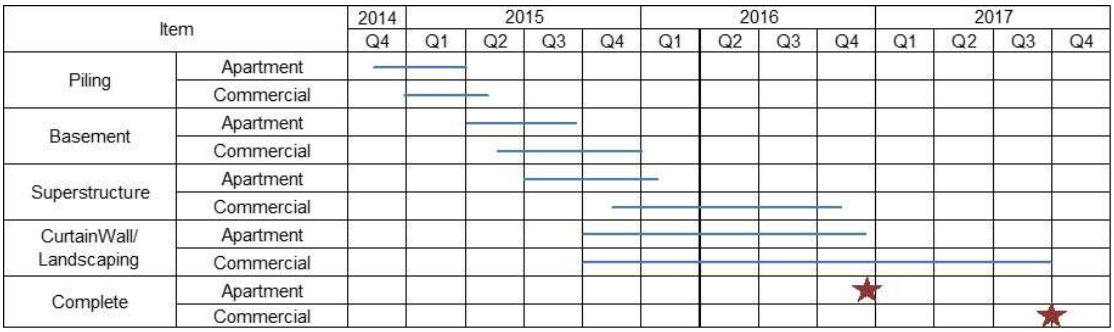


Fig. 23 – Initial Planning (Source: Author's own)

The reasons of delay can be summarized as the design changing of structure, severe weather, reworking (the quality of product cannot be accepted), the defect works, and also policy reasons leading to halt moments during the construction process (2015 World Internet Congress, 2016 G20 summit).

The residential development is handed over on May 2017, followed by soft opening of commercial on May 2018. The former was delayed by two months and the latter by five months. The main reason is that in order to cooperate with the international conference (WIC and G20), two and four weeks of shutdown, a total of one and a half months. This type of delay is uncontrollable. In the following research, I focus on the controllable factors, such as design changing, defect works and so on. Moreover, the workflow of defect works rectification cannot be ignored.

4.3.3 Quality

The quality requirement of this project meets the qualification standard of Zhejiang Province. The quality supervision department summarizes a complete set of common quality defects and treatment methods according to the maintenance of similar projects after delivery and using for the residential project, which are associated with some common defect works.

a. Structural defects

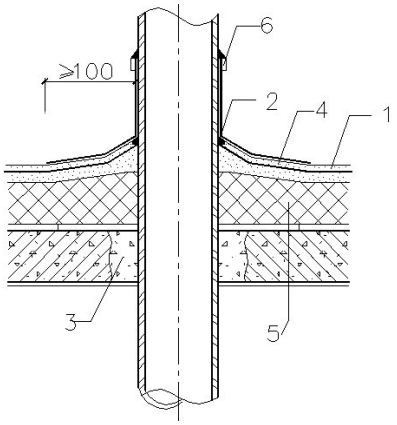
Structural defects are usually relatively rare, because in the workflow of project management, there are strict regulations on the performance of structural materials, the operation process in the construction process, and the inspection after completion of construction. The specification are relatively complete, and various indicators are also clear. What we need to implement is to strictly abide by these rules in the construction process. The mainly defects act out as crack (masonry crack and crack of concrete structure). In the crack prevention treatments, the main measures are to increase the auxiliary reinforcement and adopt a certain form of layout. Figure 24 shows the crack-proof structural steel bar of slab.

Fig. 24 – Arrangement of reinforcement
(Source: Author's own)

b. Defects of using function

Geometric dimension deviation and water seepage (external wall, windows, roof, floor, pipeline) is considered as the main defects of using function. The former defects are usually rectified by the decorative façade of the structure. The latter is a common defect, which usually needs to be avoided by careful construction. Once the contractor fails

to comply with the requirements of drawings and specifications, it is likely that water seepage will appear. The following figure shows the structure of pipe crossing the roof. The gap between pipeline and roof structure is the hidden defect of water seepage.



1-protect layer；2- sealing material ； 3-C20 concrete；
4-water proof layer；5- thermal insulation layer ； 6-
Galvanized metal hoop

Fig. 25 – Extend the roof tube (Source: Author's own)

c. Summary

In this case, quality management must not only comply with the basic management process and requirements of the client, but also meet the local specifications of the project. In the following study, the adjusted workflow combines the above content. And the BIM application is also based on mandatory specifications, which is highlighted as a key aspect of the project.

4.3.4 Safety

Standardized Atlas gives a more comprehensive and clear way to standardize the safety and protection measures in the construction site by means of sketches, three-dimensional drawings, example photographs, and simple text description. As the minimum requirement of "qualified" projects in the construction site, projects that fail to meet the requirements of the atlas cannot be rated as "qualified" projects. [B7]

The atlas is divided into nine parts. We pay more attention to the hole protection as well as to side protection, and the labor protection cannot be ignored. Figure 26 reveals the standard protection of the hole. And Figure 27 shows the protection of side.

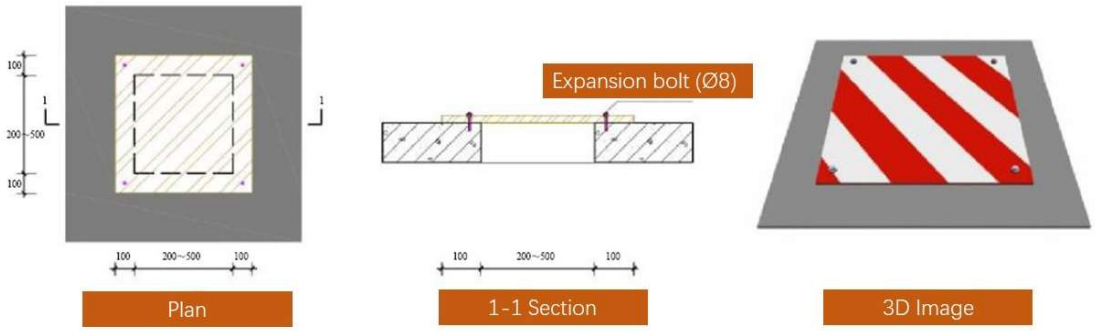


Fig. 26 – Hole protection (Source: Author's own)

4.4 Specification

As discussed in Chapter 2 and the case introduction, the specification will be illustrated in this section.

Firstly, the employer's information requirements (EIR) and common data environment will be defined and introduced. Secondly, the scope of work will be identified. The specification of modeling will be set up for different majors. Then,

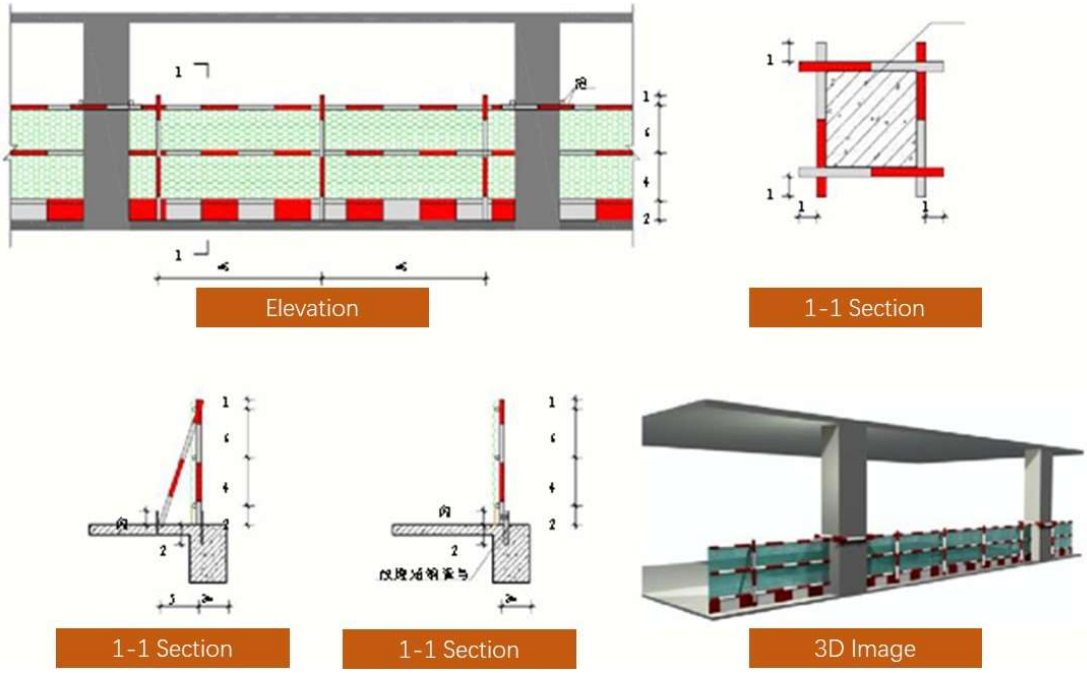


Fig. 27 – Side protection (Source: Author's own)

according to the requirements of the traditional workflow introduced in sub-section 4.3 and combined with BIM applications, the depth of the model will be clarified one by one. At the same time, the corresponding processes will be added or revised to prepare for the next research.

4.4.1 Employer information requirements (EIR)

a. Objective

The objective of BIM application is to build a visualization building information model for the project management. It can also be used as an effective tool to simulate the project planning, optimize the site administration, minimize the design mistaken with clash detection, simulate the project schedule for helping the payment. The purpose of the specification should benefit the quality of project management for the following facets shown as Table 7.

to minimize the design discrepancies, find the detection between different majors, help the design consultant improve the tender drawings and construction drawings	Client/ Designer
to reduce the uncertainties in the bidding process and reduce the rework caused by drawings deviation in the construction stage	Consultant/ Contractor
to enhance the communication between all of the participants in the project, improve the contractor for the visualization understanding for the project	All
to simulate the changing instruction, including the demolishing and rework procedure if necessary	Consultant/ Contractor
to reveal the schedule and cost influence caused by changing instruction	All
to simulate the progress of the construction, auto calculate the quantity of the completion structure, improve the quality of payment assessment by quantity surveyor	Consultant/ Contractor
to create the as-built model, calculate the quantity of work and assist the quantity surveyor to make the final account more accurately in the measurable major	All
to support 4D BIM during the construction stage, compare with the	All

actual progress of the project, improve the quality of schedule control of the project management	
to simulate the site arrangement, optimize the site administration, reduce the waste of temporary facilities	Contractor
to record the defect works and the result of rectification, improve the quality control of the project management	Client/ Supervisor/ Contractor

Tab.7 – Objectives (Source: Author's own)

b. Qualification of the team

BIM application is an innovative technology in recent years. Compared with traditional project management technology and tools, on the basis of personal experience of engineers, it is more necessary to cooperate with innovative teams to achieve BIM application goals. Therefore, it is necessary to clarify the team organization chart and related work experience.

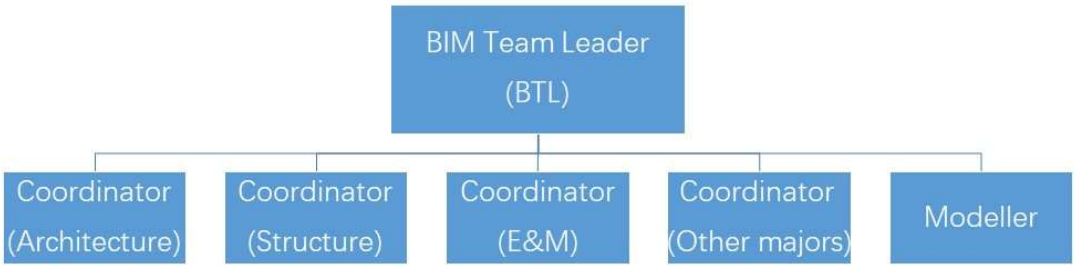


Fig.28 – OC of BIM Team (Source: Author's own)

Figure26 shows the typical organization chart of a team. The qualification of each participant is advised as the following Table8.

Team leader	Minimum 5 years practical experience in management of project, minimum 3 years practical experience in management of BIM project, familiar with the construction process of commercial projects, familiar with design, construction, cost and other items of management, good communication skills and execution ability
Coordinator	Minimum 3 years related construction project experience,

	minimum 1 year practical experience in BIM project, familiar with the design of construction, good communication skills
Modeller	Diploma holder in construction related sicipline, minimum 1 year practical experience in BIM project, familiar with modeling software, such as Revit, Tekla, Navisworks, Autodesk 360, Sketchup, Luban, Glodon, Rhino and so on.

Tab.8 – Qualification of team (Source: Author's own)

.

Each team must work on the same model of the project. The team of client need organize and coordinate all of the BIM teams. The common data enviornment (CDE) will be introduced in next section. The working mode of teams shows as Figure 29.

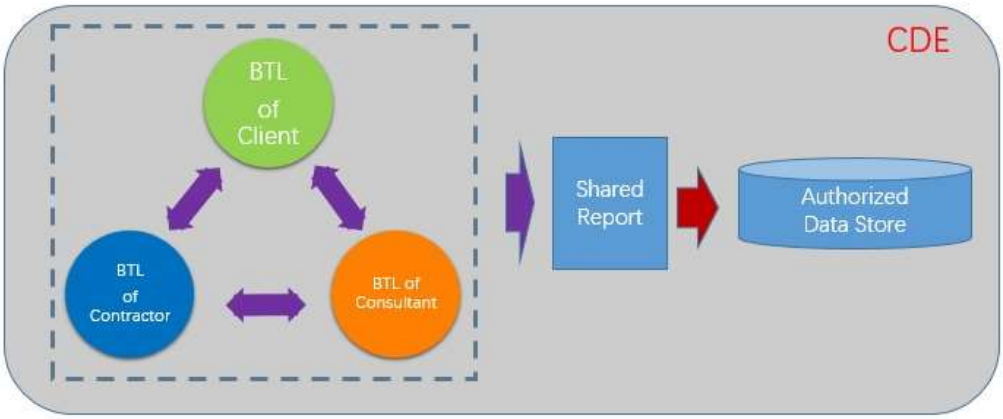


Fig.29 – BIM Team working mode (Source: Author's own)

c. Deliverables

According to the objectives of BIM applications and the requirements of project management, all the participants shall submit the following deliverables. The copyright of all data and information including BIM models and reports (all draft and final version) shall be the property of the client.

d.1 BIM model

The contents of model will be introduced in clause4.4.3. The BIM

team shall create, maintain and update the BIM model and use the model for the objective described in clause4.4.1.

d.2 3D coordination

Every participant shall submit the model as the following requirements.

In the initial stage, the design consultant shall issue the model based on the concept design.

In the shop-drawings stage, the design consultant shall detect the clash among the different majors by 3D model. The detection reports must be issued as record to the client. The rectify 3D model shall be submitted too until the clash detection decline to naught. The components of the models will be illustrated in sub-section 4.4.3.

After the letter of acceptance for the general contractor (GC) having be issued, the BIM teams (client, consultant, GC) shall cooperate together based on the specification and requirements of the contract conditions. The existing model can be authorized by the client for sharing to all the participants in CDE. As a result, the GC BIM team shall submit the site administration including the temporary facilities arrangement, the location of the crane, space of material storage, material processed area, traffic organization of construction, and so on. To follow the procedure accordingly, all members of the BIM team shall hold regular coordination meetings to communicate the construction content according to the model in the CDE, so that participants can visually understand the key contents of the construction. The consultants can follow up the work needed in time.

According to the changing instruction, the GC BIM team must update the model in the CDE. Whilst, the BTL (BIM team leader) shall notice the revised information in the record list.The consultants shall keep their mind on the sequence of model. The quantity surveyor can get the information in the regular coordination meetings and check the cost analysis during the

construction period. So that the client can obtain the financial report in time especially for the significant cost changing.

The supervisor shall point out the defect works on site and record in the model. The responsible contractor shall rectify the defect works and make the maintaining information in the model. So that the client can visually and convenient get the information.

GC BIM team shall create the roam model for the important space of the building. The space includes pump room of fire service, water pump room, power supply room, the room of fire control center, mockup space with interior decoration, etc.

d.3 4D simulation

Based on 3D model, the schedule shall be involved in the information. 4D simulation will cooperate with project management, so that participants can intuitively understand the project schedule, schedule risk, and the process of different major at the same time. The GC BIM team shall submit the following report.

Planning. The report shall include the structure simulation model and the significant temporary facilities. According to the characteristic of mix-used commercial project, the main structure, including the piling works, the retaining works, the basement construction, the structure of office tower and podium. the curtain wall works, must be created the 4D model for all participants in CDE in different stage.

The site arrangement simulation. The site facilities is included not only the temporary office, space of material storage, material processed area, but also the construction machine location and sub-contractor’s necessary requirements for the site space. Therefore, the GC BIM team must obtain all of the information for the site and combine the situation of the different period of the construction. The reports shall be stored in the CDE so that each participant can get the information and clear understanding of

the appropriate work arrangement. The simulation of the site administration can help the client reducing the waste.

Schedule control and adjustment. Based on the planning, the GC BIM team must focus on the changing instruction. All change instructions that may cause schedule delays should be pre-simulated on the model, and corresponding methods should be developed to reduce the extension of time caused by change instructions.

The GC BIM team shall submit a 4D simulation report included the containing as the followings.

- Description of the 4D simulation report, assumption, time interval, construction method statement.
- Video of 4D simulation.
- Model for 4D simulation.
- Linked schedule.

d.4 As-built model

The GC BIM team shall submit the as-built model of all components as describe in clause4.4.3. The as-built model shall be created on the final construction drawings and information that had actually built. The GC shall submit the operation data, products catalogues, operation manuals, maintenance requirements into the model. The following information must be included in the handover list: Door schedule with ironmongery list, window schedule with accessory, equipment schedule of different majors, including heating, air-conditioning, fire service, gas system, electricity, ventilation and so on, signage schedule, testing and commissioning reports.

d. Execution plan

According to the time schedule of the project, the BIM team shall submit the BIM Execution Plan (BEP). The plan must be contained with full details of the implementation and requirements of all participants. Here are some examples of the contents for the BEP.

d.1 The schedule of model deliverable.

The schedule should be submitted by GC team. It is the guidance for the participants of the project. In each stage, the client, the consultants, the contractor and the others can get the model from CDE for their own purpose. The only person who have the authorization can edit the model in CDE.

d.2 The duration of model updating.

For different majors, the time required for model making and updating is different. Therefore, the BIM teams of different majors need to make corresponding work plans according to the drawings and complexity of the project, and confirm the duration for updating the model so that the participants can arrange related work.

d.3 The schedule of as-built model.

Considered with the handover after the project completion, schedule, the as-built model shall be created in advanced. The GC BIM team and the sub-contractor BIM team must work together and confirm the schedule of issuing the as-built model. The schedule shall also include the double check time. So that the final version of model is exactly alike with the actually the building is built.

4.4.2 Common data environment (CDE)

a. Software

Figure10 shows the application of software including the domestic and international productions in Shanghai as discussed in Clause2.7. The following software for making models are acceptable: Revit, Tekla, ArchiCAD, Navisworks.

b. The file format shall be Industry Foundation Classes (IFC).

All the files must be stored in the server and protected by IT technician. The files must be made the backup once a week. The backup documents must be stored in another server, Access of the BIM Team for the sever shall be defined by the client.

c. Hardware

The computer shall be able to work smoothly during the software of modeling being using. The server must have the function of power-off protection. The storage capacity of the server should be able to match the storage requirements of models, and the specific data should be updated and expanded at any time according to the requirements.

4.4.3 Specifications of modeling

The requirements of model of each major will be identified upon several level for the different objective in lifecycle of the project. The following tables shows some main components and level of definition (LOD) of the different majors, including architecture, structure, curtain wall, electricity, fire service, burglar alarm (BA), plumbing & drainage and interior decoration.

Architecture					
Describe of components		LOD			
		100	200	300	400
(1)	site topography and buildings, including the site context of surrounding within 500 meters of the Red Line of the land	■			
(2)	Spaces, including rooms, equipment rooms, and corridors		■	■	
(3)	Slab, including floor, roof, ramp		■	■	■
(4)	Internal walls, including all the types of unstructured partitions		■	■	■
(5)	External walls, excluded the structure walls and curtain wall		■	■	■
(6)	Water proof and insulation on the external wall				■
(7)	Doors, access panels, shutters		■	■	■
(8)	Ironmongery, including doors, windows and external wall				■
(9)	Windows and louvers,		■	■	■
(10)	Frame of windows, including the ironmongery				■
(11)	Stairs		■	■	
(12)	False ceiling			■	■
(13)	Fixed furniture			■	■
(14)	Interior fitting out works of back of house, including the finishing of ceiling, wall and the floor			■	■
(15)	Signage				■

Tab.9 – Specification of architectural model (Source: Author's own)

Structure					
Describe of components		LOD			
		100	200	300	400
(1)	Pilings, such as bored pile, pre-stressed high strength concrete (PHC) pipe piles		■	■	
(2)	Pile caps		■	■	
(3)	Retaining wall and structure		■	■	
(4)	Civil air defense structure		■	■	
(5)	Columns, beams, slabs and walls		■	■	
(6)	Elevator shaft, equipment rooms made of concrete		■	■	
(7)	Steel structure		■	■	
(8)	Rivets, connectors and corbels of steel structure			■	■
(9)	Steel bars of all the structural components described above			■	
(10)	All of the holes reserved for the other majors in the structure			■	■

Tab.10 – Specification of structural model (Source: Author's own)

Curtain wall					
Describe of components		LOD			
		100	200	300	400
(1)	The structural frame works of external wall		■	■	■
(2)	Glass		■	■	
(3)	Aluminum frame system		■	■	
(4)	Ironmongery of aluminum frame system				■

Tab.11 – Specification of curtain wall model (Source: Author's own)

Mechanical and Electrical System					
Describe of components		LOD			
		100	200	300	400
(1)	Electrical system		■	■	■
	- switchboard cubicle, motor control center, outlet, power bus duct, power cable(>50mm2), cable ladder, cable tray, trunking, earth tape, down conductor		■		■
	- utility connection system, including the duct, cable, etc		■		
	- lighting		■		

(2)	Heating, Ventilation and Air-condition system				
	- chiller, pump, variable refrigerant volume units (VRV)		■		■
	- air conditioners, air-handling unit		■		■
	- ventilation, air valve, hood, air duct		■		■
	- cold chamber, water tank		■		■
(3)	Fire service				
	- fire hydrant, hose reel		■		■
	- sprinkler (including the control valve, flow switch, head)		■		■
	- detector, break-glass unit, fan-coil unit, fire extinguisher, pipe, valve		■		■
	- exit sign, directional sign, visual fire alarm, alarm bell		■		■

Tab.12 – Specification of M&E (Source: Author's own)

Burglar Alarm and Security System					
Describe of components		LOD			
		100	200	300	400
(1)	Release button of door, access card reader, CCTV camera		■		■
(2)	Inspector patrol point, security detector		■		■
(3)	central security server console, panel		■		■

Tab.13 – Specification of BA system (Source: Author's own)

Plumbing and Drainage System					
Describe of components		LOD			
		100	200	300	400
(1)	Water tank, pump, filter, pipe		■		■
(2)	Pipe, gully, drain outlet, sewage pump		■		■

Tab.14 – Specification of plumbing and drainage system (Source: Author's own)

Interior Decoration					
Describe of components		LOD			
		100	200	300	400

(1)	Floor decoration				
	- tile/wooden/marble floors, mosaic, including different types of materials		■		
	- elevated floor, including the accessories		■		■
	- antistatic floor and all necessary accessories		■		■
	- carpet		■		
(2)	Wall decoration with all types of material		■		
(3)	Ceiling				
	- aluminum		■		
	- plasterboard/waterproof plasterboard		■		
	- stainless steel/ glass		■		
	- canopy		■		
(4)	Loose furniture		■		
(5)	Fixed furniture				

Tab.15 – Specification of interior decoration (Source: Author's own)

The content of the model is described in detail in the list above. According to the requirements in different stage, the distinct LOD shall be considered separately within model making. Table16 shows the requirements for model depth at different stages and objectives. It can be used for the BIM application in the revised workflows. Each BIM team can follow up for model making and using.

Specification of Model Depth					
Stages and Objectives		LOD			
		100	200	300	400
(1)	Concept design				
	- Site administration	■			
	- Building model (architecture/curtain wall) for 4D simulation		■		
(2)	Tender drawings and construction drawings		■		
	- Clash detection				■
	- Revised drawings and models				■
(3)	Construction Stage				
	- Changing instruction				■

	- Payment review				■
	- Schedule control		■		
	- 4D simulation for coordination between different majors			■	
	- Site arrangement			■	
	- Defect works rectified				■
(4)	Completion				
	- Quantity review for final account				■
	- Record of defect works				■
	- As-built model for asset management				■

Tab.16 – Model depth (Source: Author's own)

Note: LOD100-200 is defined as level 1, LOD300 is defined as level 2, LOD400 is defined as level3 (applicable to the Table 9 ~ Table16)

4.4.4 Scope of work

The scope of work is the basic rules of the EIR. This is demonstrated as below:

a. All of the BIM teams are required to apply BIM applications for the project management during the lifecycle of the project.

b. The BIM Team Leader (BTL) shall carry out the following duties.
   - b.1 Prepare the BIM project execution plan (BEP).
   - b.2 Manage the BIM team, including providing the results of working, being responsible for the whole BIM management by the client.
   - b.3 Coordinate with all of participants based on the specifications and workflows of project management.
   - b.4 Plan, update and implement the project BIM specifications.
   - b.5 Plan and implement the quality control procedures.
   - b.6 Provide monthly report about the BEP progress.

c. The BIM Team shall provide the following services.
   - c.1 To coordinate all other teams.
   - c.2 To build and develop the models in the CDE, manage the databases.
   - c.3 To report the result of work and combine the reports in the CDE.

c.4 To optimize the schedule/cost with the BIM application, analysis the optimization achievement.

c.5 To cooperate with design consultant, input the updated information and data in the CDE, and update the models due to all variations.

c.6 To ensure the updated models kept ahead of the site construction.

4.4.5 Time schedule

All project participants must follow the schedule of implementation of BIM application as the followings.

a. The duration of model making shall comply with the following requirements.

a.1 Architectural and structural models, within 3 months from the Letter of Acceptance being issued.

a.2 M&E system, BA system, Plumbing and Drainage system models, within 3 months from the Letter of Acceptance being issued.

a.3 Curtain wall models, within 2 months from the Letter of Acceptance being issued.

a.4 Interior decoration models, within 2 months from the Letter of Acceptance being issued.

All teams shall submit the organization chart and qualification of members for the client's (BTL) approval within 21 calendar days after the commencement of the contract.

b. All teams shall submit the conflict detection reports to the client (BTL) within 7 calendar days after the model been confirmed. And the reports must be submitted at least one month before the construction of those elements.

c. The design consultant shall revise the drawings and model within 21 calendar days after the conflict detection reports been issued.

d. 4D simulation reports shall be issued at least 21 calendar days in

advance of the nominated construction.

e. The duration of quantity auto-measurement shall be discussed and confirmed by the quantity surveyor BIM team and the client depending on the complexity of the object.

f. 3D coordination shall be submitted according to the project progress.

g. As-built BIM models shall be submitted within 6 months after the certification of completion of the project.

4.5 New workflow of PM

4.5.1 Introduction

We have introduced the traditional workflows in clause4.2. They are widely used in the project management for the mix-used commercial project. This section will focus on the new workflows based on BIM applications. As discussed in Chapter1 and Chapter3, optimizing the workflows of the project management shall be combined with the applications of BIM. The detail of specification of BIM has been studied in clause4.4. According to the case study, this section will try to seek a substitute for the artificial decision-making by the auto analysis according to the applications of BIM in those workflows.

4.5.2 Tender process

Figure 10 shows the tender process. The significant part is the preparation of tender documents and the analysis of quotation. These two parts define the rights and responsibilities of both parties and the requirements of the contract. They also define the quality of contract management and construction management, which plays a key role in the success of the project.

As discussed in clause4.2.1, the time of tender is used to be effected by lots of uncertain conditions which must be clarified because of the quality of the tender drawings. Therefore, the clash detection of tender drawings must be completed before the tender documents being issued. The workflow of model detection will be added to the preparation stage of tradition workflow shown as Figure 30.

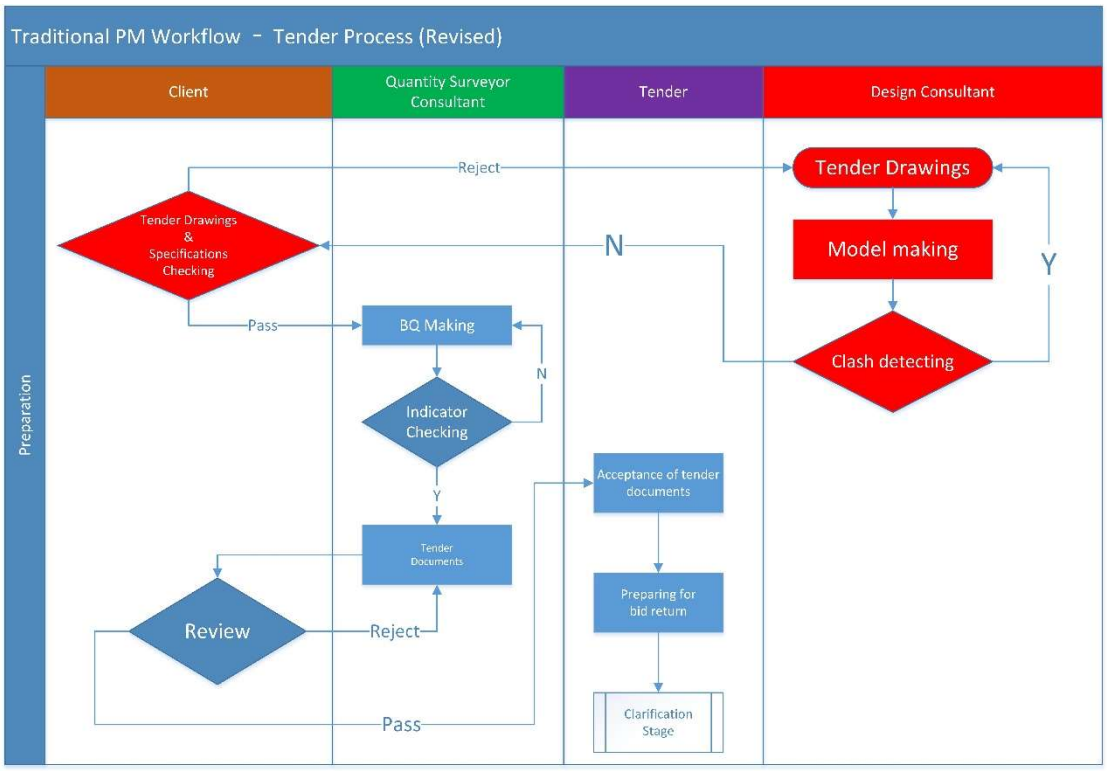
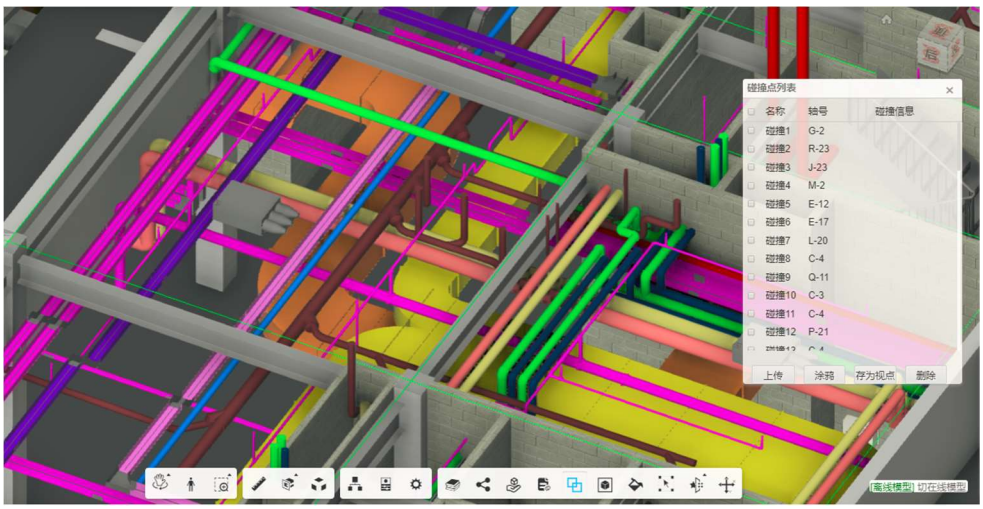


Fig.30 – Revised Tender process (Source: Author's own)



Design Clash Detection (Source: Author's own)

In the new workflow, the clash detection of tender drawings will be finished before the drawings issued to the client (Highlight with RED). These will reduce the mistaken in tender drawings and help to reduce the clarification time in the next stage, so that the client can have more time to focus on quotation itself rather than repeatedly explain drawings. The changing instruction will also be reduced due to more accurate drawings in the construction period. Moreover, Cost, as one of the most important part of project management, will be controlled accordingly.

4.5.3 Changing instruction

In addition to the change instructions caused by drawings errors in the construction stage, the drawings adjustment caused by demand changes will also occur corresponding change instructions in the construction stage, which will not only lead to increased costs, but also have a negative impact

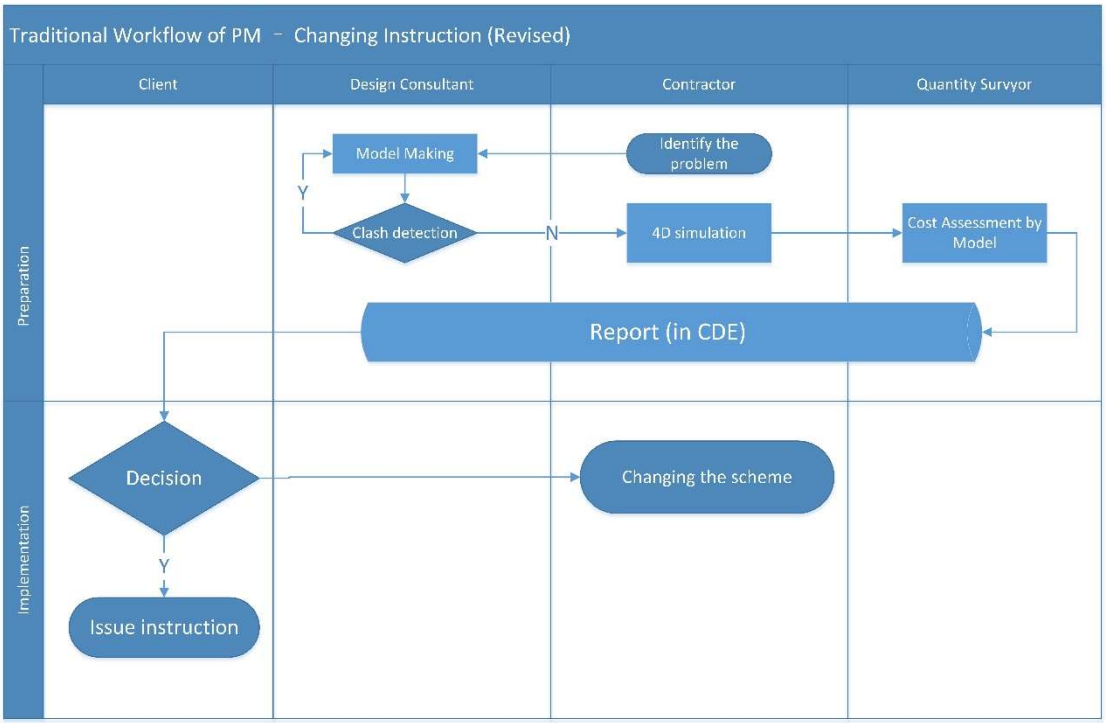


Fig.31 – Revised changing instruction (Source: Author's own)

on the duration of the project. Figure 15 shows the traditional workflow of changing instruction. The assessment of cost and schedule will be analyzed separately by the quantity surveyor and the contractor. The revised workflow will combine the assessment by the BIM team. The report will

be a visualization one to the client.

Figure 31 shows the new workflow of changing instruction. The analysis of the instruction will be based on the same model by the consultant. And all of the information will be stored in the CDE. The affective of time and cost would be revealed in the model. The client will obtain the whole data by the visualized model and make the decision more efficient.

4.5.4 Payment

There are three steps of decision making in the traditional workflow of payment (Figure 14). In the process of payment, all parties have their own understanding of the progress, which leads to more communication time and longer payment cycle. In practice, the contractor's passive excess will delay the construction progress because the payment amount cannot be agreed. The new workflow can be abridged and there is only one decision making by the client (Figure 32).

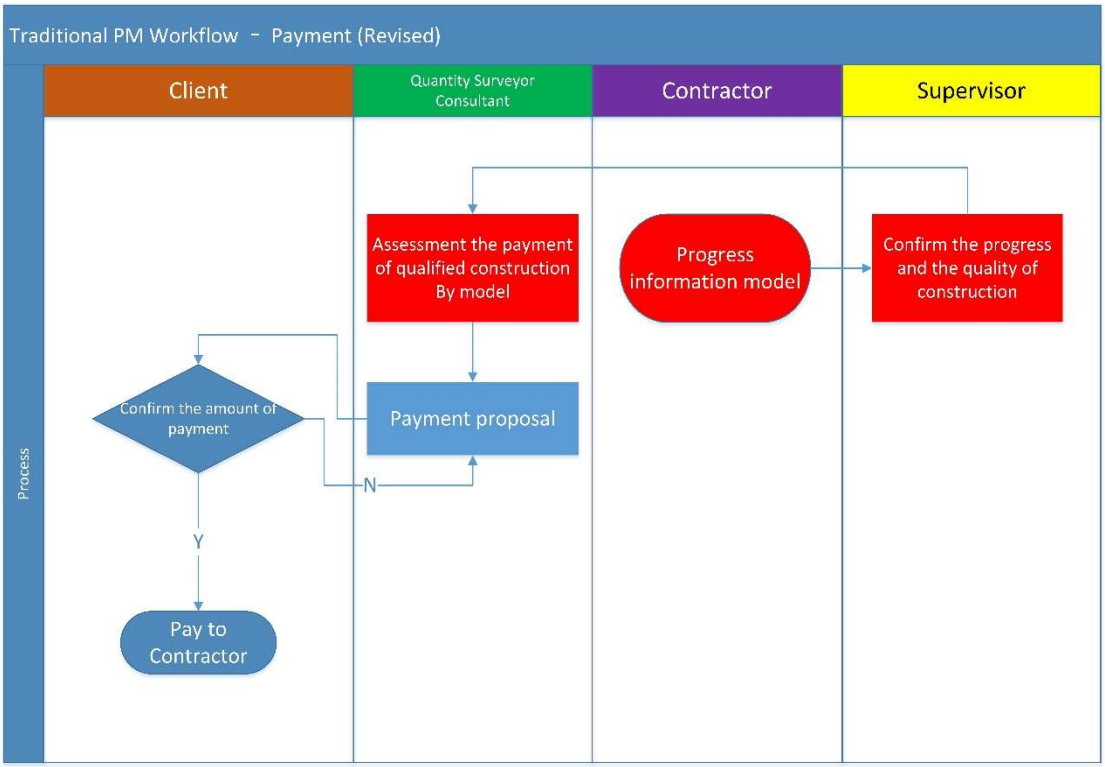


Fig.32 – Revised payment process (Source: Author's own)

In this workflow, the red part will be involved in the CDE. All information can be confirmed by the responsible participant. The progress of the

construction will be input by the contractor and confirmed by the project supervisor. The un-qualified construction area will be point out by the supervisor in the model. The quantity surveyor must apprise the qualified construction by the model. All this process does not need the decision making. Whilst, the information is stored in the CDE so that each participant can obtain the information of progress by the authorized. It is obviously that there will be no more negotiation between the client and the contractor. The contractor will pay more attention to the construction.

4.5.5 Final account

Based on the provided discussions, the new workflow is shown as Figure 33.

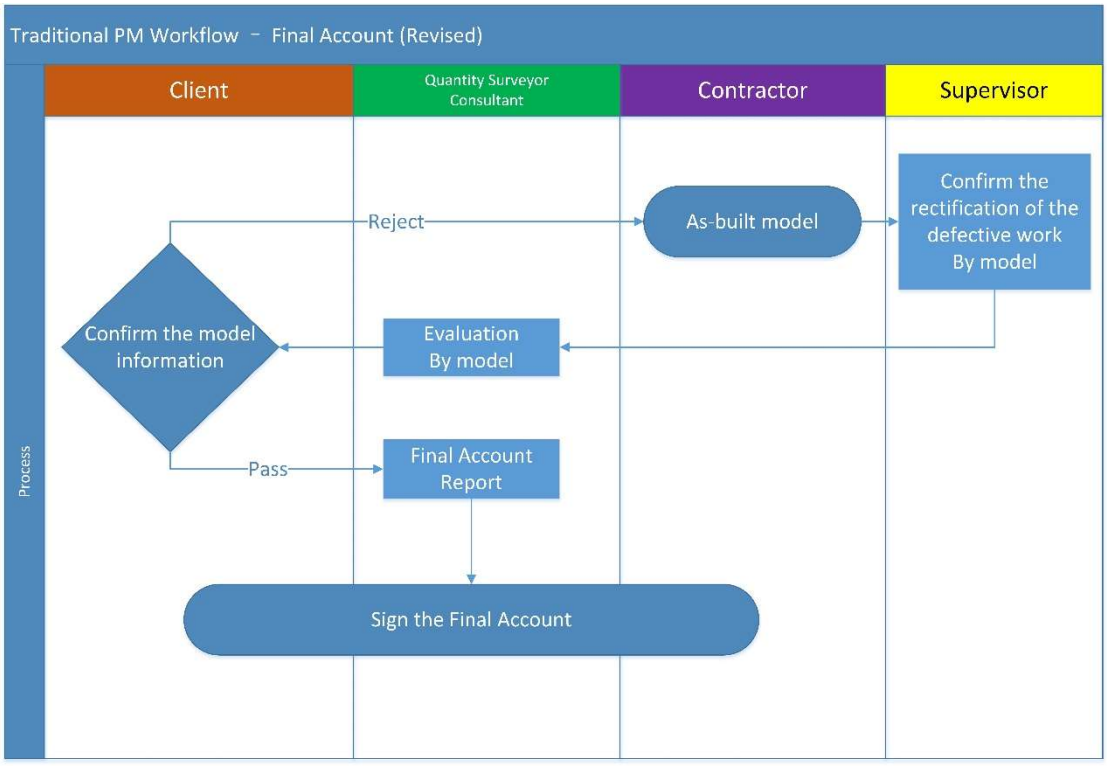


Fig.33 – Revised final account process (Source: Author's own)

As-built model will include all of the information matched the realities. The supervisor should confirm the defective works whether be rectified already or not. Then the quantity surveyor will assess the valuation of the as-built model exclude the permanent defect claim by the client. And the client also assesses the model in the CDE. The negotiation process in the traditional workflow has been deleted. It is replaced by as-built model information. All of the information in the CDE will be updated in the

construction period and confirmed by all project participants. Therefore, the new workflow will be better for each participant.

4.5.6 Planning

The new workflow (Figure 34) revises the responsibility of contractor for the schedule control. The contractor must be full responsibility to the construction schedule. 4D simulation can help all the participants understanding the situation of the construction. The supervisor must review the construction model in order to make sure about the correct model.

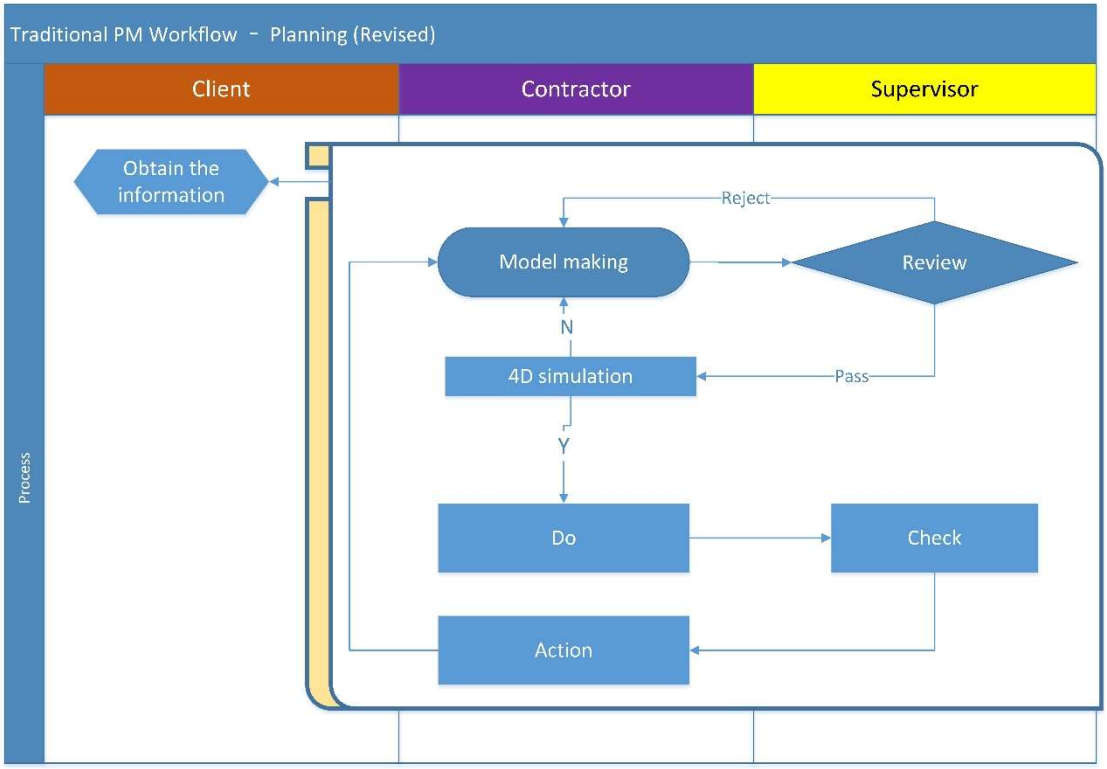
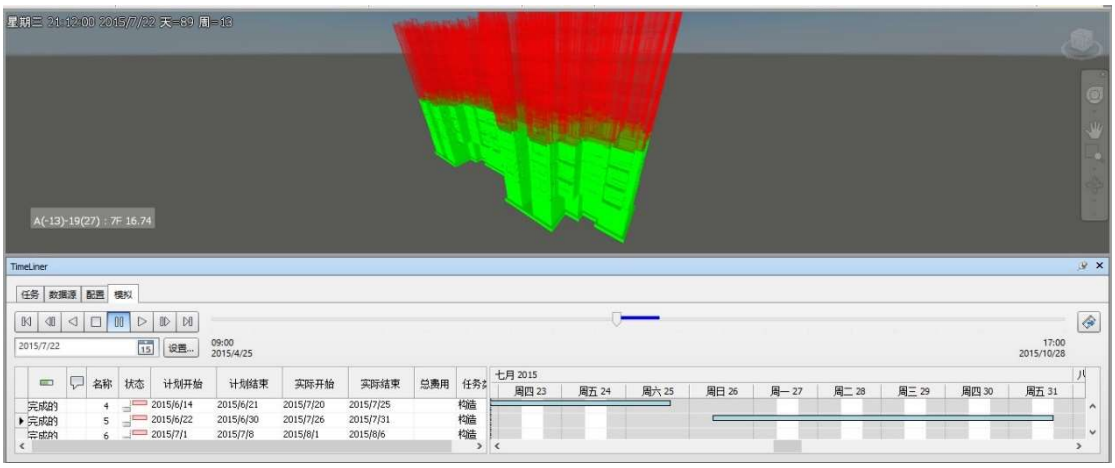


Fig.34 – Revised planning (Source: Author's own)



4D Simulation

The client can obtain the information from the CDE. In the construction process, the contractor can also be instructed to adjust the schedule according to the results of 4D simulation by the client.

4.5.7 Site arrangement

The general contractor usually takes the responsibility of the site arrangement. And the preliminary fee of the temporary facility is often a

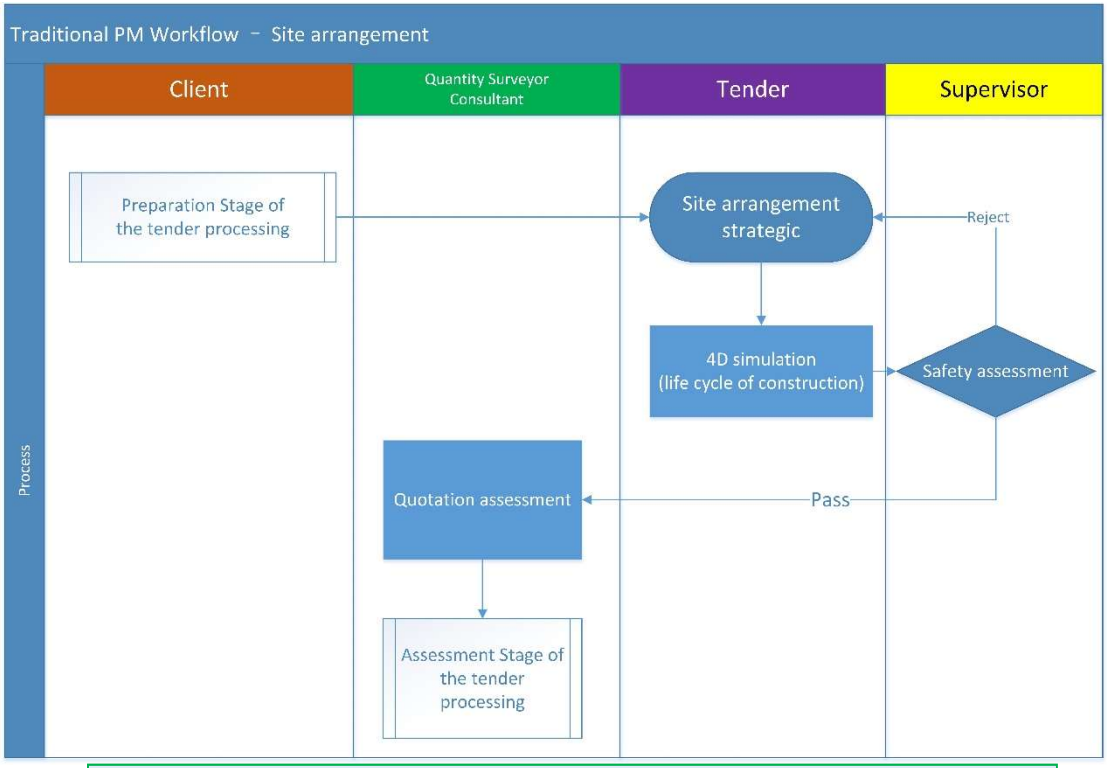


Fig.35 – Site Arrangement (Source: Author's own)

lump sum in the contract amount. So the only chance for the client to optimize the cost is to make the analysis in the tender evaluation. As discussed in clause 4.5.2, tender assessment is relatively short. So how to effectively evaluate the reasonable layout of temporary facilities in the tender process has become the key work to control this part of the cost.

The new workflow will focus on the bidder's strategic. The layout of the site and all the types of the equipment in the construction period will be simulated. And this would help the quantity surveyor to apprise the quotation of the bidder. The cost will be more clearly according to the simulation. Figure 35 shows the new workflow.

The safety assessment will be the additional decision in this new workflow. This will contribute to the pre-control of safety management.

4.5.8 Defective works rectified

Figure 36 shows the new workflow of the defective works rectified.

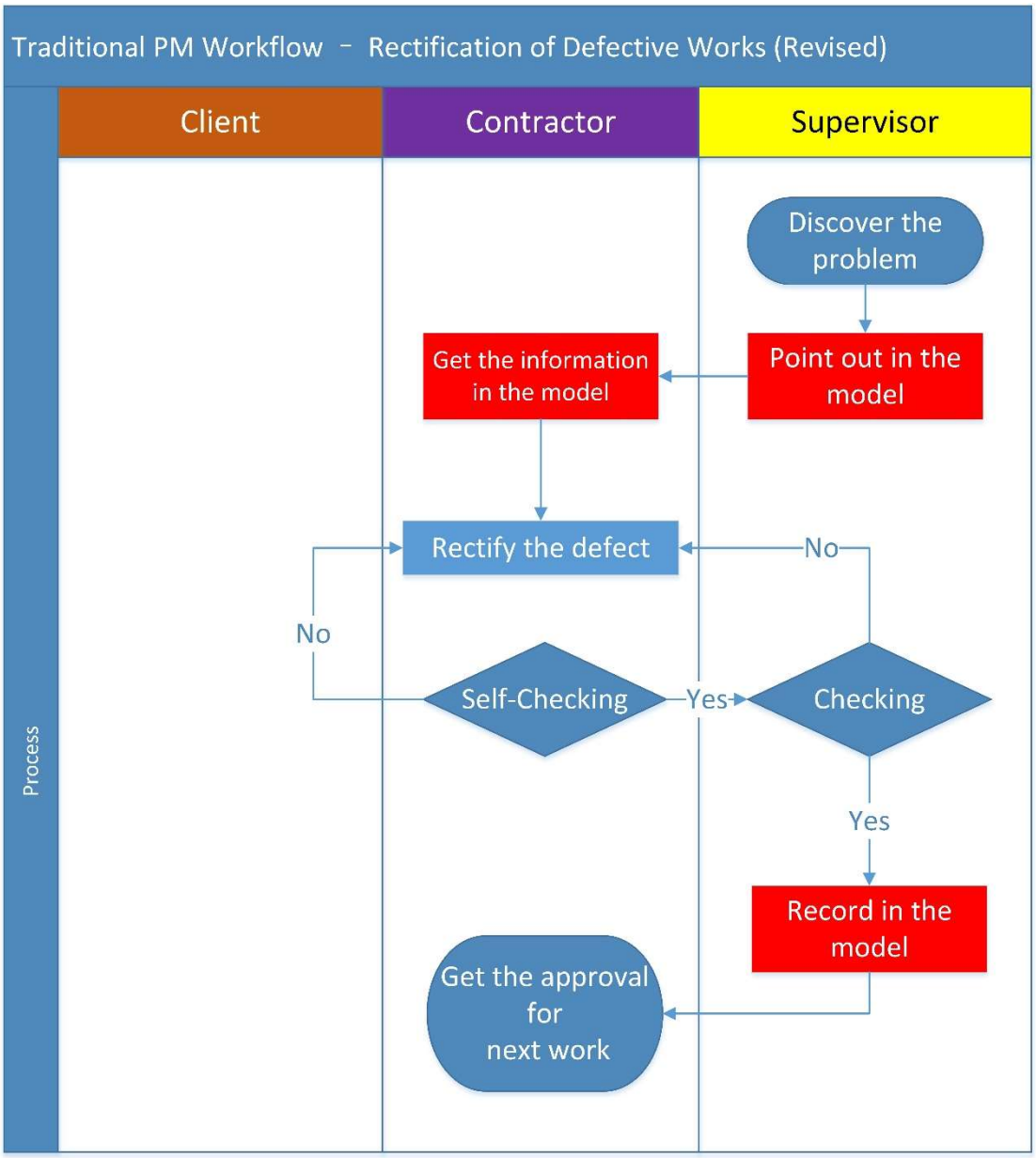


Fig.36 – Rectification of defective works (revised) (Source: Author's own)

The red parts substitute the traditional one by the BIM application. The information will be stored in the CDE. And in the final account process, the defective works will be considered for the valuation as discussed in clause4.5.5. All of the defective works will be shown in the model. The

operation department can also get the information from the as-built model so that they can pay attention to the section.

4.6 Practical example for tender process

4.6.1 Introduction

The new project is situated in Hongkou District of Shanghai, which is a mix-used commercial project including preservation buildings and new buildings. As discussed in section 4.5.2, new workflow of tender process was applied in this project. This section will introduce the practical applications of preservation buildings and new buildings.

4.6.2 Tender of preservation buildings

According to the contract, the existing conservation buildings cannot be demolished. All of the preservation buildings should be renovated as the original design. In fact, the government had demolished some components of the old buildings before the land was sold (Figure 37: the photo of site).

Fig.37 – Site photo (Source: Author's own)

These are the typical Shikumen-style building. Some of roofs and beams were demolished. The scope of work for tender includes rebuild the roofs

and beams. The drawings of existing buildings were surveyed by the consultant. The tender should visit the site and make it clear about the scope of works. In the traditional workflow, after the surveying the site, the quantity surveyor should create the bills of quantity of tender documents. However, the circumstance of each unit of old buildings is different. At the same time, the interior situation of unit is also complex. So the consultant cannot accurately describe the bills of quantity.

According to the new workflow of tender process, the developer selected one unit of old buildings and invited consultants to conduct a three-dimensional scan of the building. It took about 2 weeks for scanning. The result of scanning was submitted to the consultant (shown as Figure 38). Each part of the old building can be calculated and described clearly. And the tender can also make the quotation accurately by this document. This sharply reduces the claim risk in subsequent contract management due to unclear work content during bidding stage.

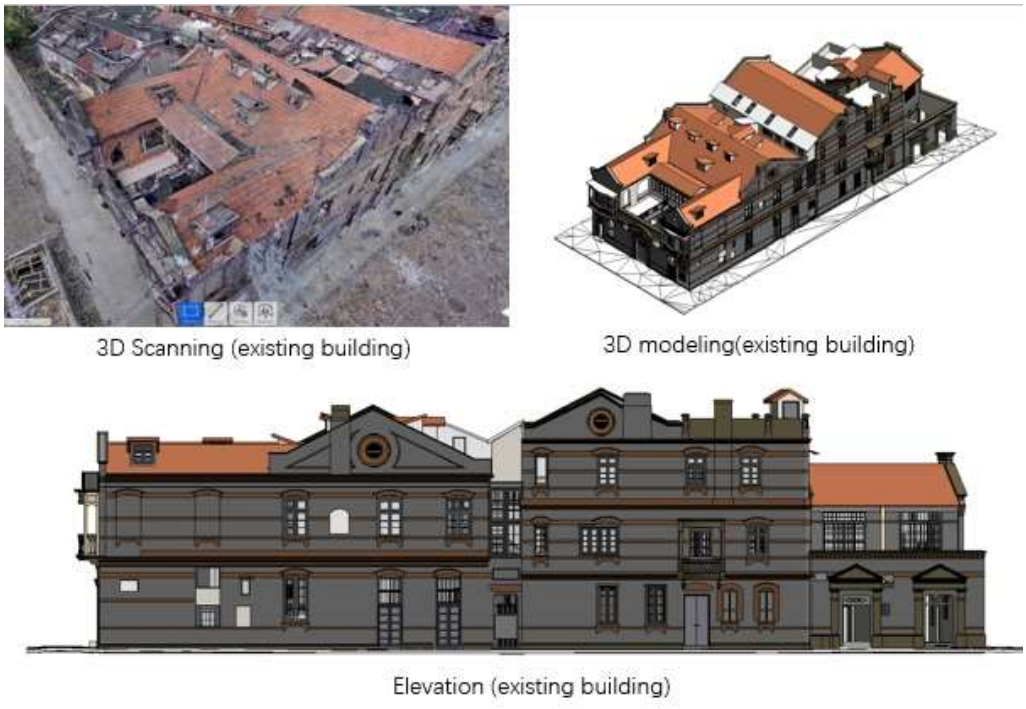


Fig.38 – 3D Scanning (Source: Author's own)

4.6.3 Optimization results and discussion

The modeling established by 3D scanning can make all of the participants understand the project situation more clearly. Although in this practice, no detailed information has been input into the model. But in the bidding stage, it can effectively solve the important information that 2D drawings cannot express.

It is obviously that the new workflow can help the developer for cost control in contract management. But the schedule should be optimized. In this case, compared with the traditional tender workflow, the work of scanning and the time of making modeling are totally new milestone and need to be further optimized in the next research.

4.7 Summary

There are four parameters in project management shown as Figure 39.

Fig.39 – **Parameters of Project Management** (Source: Author's own)

Contract is the principle of project management. The traditional project workflows focus on the four parameters. All the facets of project management are based on the contract conditions.

Cost refers to all production costs included in the process of construction project implementation. Cost management means taking management measures to

control the cost within the planned scope and further seek the maximum cost saving under the condition of ensuring the construction schedule and quality. The purpose of schedule control is to achieve the progress goal of the project through control. The control method includes the analysis of progress target, the preparation of progress plan based on the collection of data and investigation, the tracking inspection and adjustment of progress plan. Quality management means commanding and controlling the project participants to coordinate with each other on quality in the process of project implementation, so that the project can meet the quality requirements. Health and safety refers to the conditions and factors affecting the health and safety of employees or other employees, visitors or any other personnel in the workplace.

4.7.1 Cost

As discussed in Chapter 2 and section 4.2.1, cost control is the significant component of the project management. It is generally acknowledged that one criterion for judging the success of a construction project is whether it is completed within budget. The influential factors of cost, such as delay in progress payments by clients, difficulties in financing project by contractors[27], changing of material price, become a risk to be considered in the budget.

More and more people begin to pay attention to the life cycle cost (LCC), which is included project feasibility study, design, construction, delivery, operation and maintenance. Life cycle costing may be performed as part of feasibility studies to find the most cost efficient solution, as part of a detailed design to determine an in-service budget for the owner, as part of the tender to assess the most economical bid proposal, or as part of the procedure to choose the optimum operation and maintenance strategy. [28]

The estimation at the initial stage of the project determines the cost target of the project and affects the delivery standard. The budget is usually assessed by the quantity surveyor. They collate and count the economic indicators of completed projects, and use them as the basis for new project

estimation. This is the traditional way of learning. Levente Mályusz reveals that learning does not only affect time, it has consequences on project cost as well. [29] In Nabil Al-Hazim's research, the results show that the most critical factors are terrain conditions; weather conditions; variation orders and unavailability of labors. [30] On the other hand, the design error and design change will take the increase of the cost. Oluwaseun Sunday reveals that poor construction drawing and lack of coordination among documents are the major causes of variation. He points out that designers pay more attention to drawings than specifications. [31] In this research, the workflow of variation orders has been revised. The specifications of BIM applications are issued at the same time.

4.7.2 Schedule

The environment, the cost, the quality of construction in the construction process, will affect the construction schedule management. It is necessary to make reasonable arrangements for the construction content according to the actual situation. Doing a good job on the construction site control and making a site layout plan and preparations for large machinery to approach in the construction in advance. [32]

In schedule management, Gantt provides the simplicity and responsiveness required for the day-to-day communication in projects, and was perceived as the easiest to use. Flow line was perceived as less intuitive. 4D BIM has the clarity required for conveying the bigger picture, yet was perceived as most useful for early project stages. [33] 4D simulation can make participants understand the progress of the project more intuitively, and arrange labor, materials and equipment to avoid delay on milestone.

4.7.3 Quality

The optimized workflow mentioned in Chapter 4 is based on the application of BIM. In the process of implementation, it should be combined with the employer information requirements, specifications,

and improve the management efficiency and quality according to the objective in the process. Taking the payment process as an example, the supervisor determines the progress and quality of the project on the model, which can use the visual application to reveal the information to the quantity surveyor consultant. It avoids the time extension of payment process caused by different subjective opinions of each participant in the traditional workflow.

Mix-used commercial project contains lot of risks due to the complicated nature. The attitude of construction project participants is significant to the quality control for the project. International Organization for Standardization (ISO) defined quality as “the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs”. In Turgut Acıkara’s research, he makes a conclusion that most of the project participants focus on their own task instead of the total quality of the project. [34] So the project model enables all participants to understand the quality requirements of the whole project. In the revised quality management workflow, they can be engaged in prior controlling, construction controlling. Therefore, the quality management can be comprehensively and effectively carried out.

The quality control system should be established and used in the stage of construction. Construction simulation and the actual construction of the combination of contrast effectively avoid quality problems. [35]

4.7.4 Safety

In traditional workflow, safety management is carried out by means of error-prone and inefficient manual observation. Health and safety (H&S) coordinators are still lack of effective collaboration. Vito Getuli illustrates the safety planning in construction and works in the direction a BIM-based Rule Checking with 4D planning in order to connect the static validation of a construction site configuration with the dynamic analysis of activities and related flow of resources.[36]

Design for Safety has been considered as an effective approach to improving construction safety performance via taking into account safety problems during design. GuoHongling developed a safety rule and BIM based platform to solve the problem. [37]

In this study, the application of four-dimensional simulation can not only help the construction participants to understand the overall quality management, but also understand the potential safety hazards before construction and make corresponding preparations in advance according to virtual reality.

According to the case study of the mix-used commercial project, the revised workflows of project management have been suggested in this chapter. The purpose of the research is trying to enhance the quality of project management, which focus on the cost, time, schedule and safety. Each adjusted workflow is based on the traditional one and combined with the BIM application. The characteristics of BIM should be fulfilled in the principal of the new workflow.
Starting with the details of cost control, schedule control and quality control, we make full use of the visualization of the model and the CDE. It effectively improves the communication efficiency of all participants in the construction period, reduces the evaluation time in the traditional workflow. And at the same time, the quantity surveyor consultant can understand the construction process, thus making the evaluation results more acceptable by all participants. These new workflow is expected to be used in the new mix-used commercial project.
As discussed in section 4.6 by practical experiment, the new workflow can help the developer enhance the quality of tender processing. The modeling can also be applied to reduce drawing errors and improve the quality of tender drawings, so as to avoid the risk of cost control caused by changes after signing the contract by the new workflow.

Although the advantage of the BIM application for the workflow of project management can be seen so obviously, there are still some disadvantages in contemporary applications. This research will discuss the disadvantages in the next chapter.

Chapter 5 Discussion and Conclusion

5.1 Introduction

According to the literature review and the case study review of the project, we have a preliminary understanding of the BIM standard and its application in the process of PM. The case study shows some new workflows for the project management based on the BIM applications, which will enhance the quality of project management for a mix-used commercial project.

Globally, the application of BIM has gain substantial attention in both practice and scholarly work. This is more evident in recent years and as part of the rapid development occurring in some countries in China, and also rapid digitization of the AEC industry. As argued earlier, among the many BIM standards, the BSI (British Standards Institution) standard is identified as the most comprehensive standard, which also actively promotes the application of BIM Level 2 and Level 3. China's standards are in the process of gradual improvement. However, due to the large number of construction projects in China and the vigorous implementation of BIM by governments at all levels, there are more actual cases of BIM applications.

As discussed in Chapter 2 and Chapter 4, the main application is highlighted as the followings:

- The proposed project in the three-dimensional model roaming, feel the scale of the design space in advance, while optimizing the use of space;
- Design conflict inspection helps design correct errors and omissions, and reduces cost and time loss during construction;
- To help the project management team to understand the whole construction process more intuitively, and to solve the difficult problems in the process of project construction;
- During the operation and maintenance stage, it is more convenient to browse the device information quickly through the model.

The aim of this research is a combined objective of BIM application for optimizing

the workflow of the project management, which is clearly highlighted in the case study section and analysis. In this regard, the specification of BIM applications is developed for the mix-used commercial project and for appropriating the revised workflow of the project. This is occurred in order to enhance the quality of project management and its process as a whole for project delivery.

5.2 Discussion

5.2.1 Opportunities for future applications

According to the results acquired from this research, we can obviously find out some advantages of the BIM application to the new workflow for enhancing the quality of project management. These include:

a. Reducing the cost

The cost controlling should be mainly focused on the design development process. The foremost reasons for cost wastage are mistakes that often occure at the design stage. 3D coordination can solve the problem by conflict checking before construction process, which is important to the overall project workflow. As discussed in Chapter 4, the design consultant shall revise the mistakes and conflicts of drawings after clash detection.

On the other hand, the 4D simulation of the project can help the project management team to understand the progress of the project in advance, and prepare in advance for the important work to avoid unnecessary rework and waste. The application of site administration can also help the contractor optimizing the facilities arrangement for reducing the cost. At the same time, it can help the contractor more accurate in preparing materials in time without wasting.

Whilst, the 3D coordination for the schedule control will achieve the objective of time. The potential cost, such as administration fee, cost due to the contactor’s claim for the construction delay, income from tenant due to delayed opening and so on.

b. More efficient coordination and communication

In the process of coordination and communication, the traditional method of project management mainly discusses the implementation of the project according to the blueprint drawings. The wrong version of the drawings, or the discussion of the drawings are not the same version, will lead to misunderstandings in communication, thus affecting the progress and quality of project management.

According to the research described in Chapter 4, the confirmed models in CDE will be the only documents for all of the participants. The project team must work on the same models, which are issued by GC BIM team or design consultant. The revised information can also be submitted in time due to the workflow shown in the research. Therefore, all stakeholders of the project can get the exact information of the project process and models that are used concurrently in the overall process. Therefore, the communication amongst the participants of the project will focus on the problem itself. It does not happen that the drawings are not the latest version after two hours of discussion.

The visualization and the simulation of BIM characteristics would help the team have a unified understanding of the project by reading and learning the model and the various documents derived from the model.

c. Complete and accurate information

In the traditional project management model, each participant is used to implement according to their own experience and habits. Based on national standards, local policies and regulations, many details of project management, such as construction information, document storage, etc. have not been effectively unified in the overall project management. In particular, the lack of data is often found in the production of completed files.

However, the model can record all the information from design, construction to completion in detail and accurately, so the final version

of models will accurately reflect the actual construction.

As discussed in Chapter 4, this research will provide a system of standard for the BIM application in the workflow of project management. These specifications include the objective, the qualification of BIM team, the rules of the documentation, the workflow of integrate BIM into the traditional method of project management.

5.2.2 Limitations

There are some obstacle in the research, which are highlighted in detail. These shortcomings are mainly reflected in the time of model making and updating, the automatic measurement of quantities by using model, the training of BIM specification, application and related workflow.

Although governments are promoting the application of BIM in recent years, the number of relevant professional practitioners is still relatively scarce, and the application of BIM is mainly reflected in the aspects of clash detection, space roaming and so on. However, the management and application of information are yet to be studied in depth. This makes this field of research novel, and provides further opportunity for new research and applications. Hence, it is important that the findings of this project are then used further for future research of the same mainstream.

a. The time of model making

   With the development of technology and the recognition of BIM application in the market, more and more projects need to be modeled. However, there is a shortage of people who have the ability to model professionally. At the same time, considering the requirement of model quality, modeling time has become a major problem that restricts the application of BIM. For example, People with one year's modeling experience are about 500 square meters per day in the process of building structural models. If there are more complex structural forms, the modeling efficiency is lower.

Therefore, considering the establishment of family library system for standard building products will speed up the modeling speed to a certain extent. However, architectural design is usually unique, so this method is only applicable to enterprises with a single form of building products, such as those focusing on the development of residential projects.

b. Quantity automatic measurement

The results of automatic measurement will be affected by the accuracy of the model. It will issue the wrong data because of the incorrect model. So model making and checking will be the significant workflow in the project management.

In addition, even though the model is accurate, the default deduction rules for overlapping parts of different components are different due to different habits of the modelers, which may not necessarily match the contract calculation rules.

So it is important to establish the standards of modelling, which can match the contract conditions. The calculation rules and the explanation of unit price should be considered. And at the same time, the standard should be accepted by all of the participants, such as quantity surveyor and contractors and so on.

As discussed in Chapter4, the specification of model is identified. But I only define the contents of model. The detail of model technic, such as how to establish the column and slab, which component shall involve the information of overlap part, has not been researched in this thesis.

c. Model revision during construction period

In the construction period, the design is probably to be modified. So the modelling should be revised at the same time. But the reality phenomena proved this action is difficult to be followed by the BIM consultant.

The main reason is that BIM consultants cannot get the relevant design information as soon as possible. In general, the design consultant notifies the project manager of the design revision, and the project manager pays attention to the impact of the decision on the construction period and cost. So that he would communicates with the contractor and the quantity surveyor. Usually, the information for BIM consultant will be ignored.

So in this research, the revised workflows have been made based on the Common Data Environment (CDE). It can help all of the participants transiting the information more effective. The workflow can help the client to obtain comprehensive information before making a decision, so as to avoid the wrong decision caused by design changes and model adjustment information errors.

d. Training

The establishment of the model, the use of the model, the common understanding of BIM application, especially the specification mentioned in Chapter4, the confirmation of basic requirements such as CDE, EIR, etc., all participants in the project need to be trained. This kind of training needs professional guidance, which will bring extra cost to the client compared with the traditional project management methods. At the same time, in addition to the cost for the client, the participants also need to use additional human resources. For the current requirements of AEC industry in China, the situation is disliked by many clients.

5.2.3 Other applications

This research mainly focuses on construction stage. There are lots of applications in AEC industry by the other researchers, which is excluded in the research and can be combined in the future research.

a. As discussed in Chapter 4, 3D modeling can be input the information of schedule and cost, which is called 5D BIM. Georgios Kapogiannis

reveals that economic, social and environmental characteristics are likely to be subject to change over time [38]. His study identify key uncertainties that could help project stakeholders to make early and efficient decisions.

b. Optimization of design can include not only the clash detection but also the structure design. Eleftheriadis presents an integrated design approach for the cost and embodied carbon optimization of reinforced concrete structures based on BIM in initial design stage. He illustrates that the structural layout and the slab thickness are amongst the most important design optimization parameters [39]. The aim of his another study was to develop and test a systematic participatory model that utilizes BIM-enabled technologies for data collection and group decision-making theory [40]. By identifying decision priorities for the structural system, it is deeper applications of BIM in the project development. In Ugliotti's research, BIM model of the school complex has been created putting together the geometric information and the diagnostic analysis by data collecting and geometric surveying [41].

c. Caetano has studied the applications in facade design, where he describes and develops a set of parametric facades for a residential building [42]. Gan gives an example for analyzing the effect of natural ventilation on thermal comfort and energy performance in buildings [43]. He reveals that BIM can provide information related to building geometry, materials, and outdoor environment. These are all good researches on BIM application for design purpose.

d. More attention has been given to the consideration of building and built environment in the AEC industry. The construction options can be test by using conceptual BIM models. For instance, in Röck's research, he presents a workflow for different design and construction options in early design stages by applying a BIM-integrated calculation of embodied impacts [44].

e. Although BIM adoption is growing in recent years, it is relatively weak

within operational and maintenance. The research by Heaton outlines a methodology that enables extraction of BIM-related data directly from a model into a relational database for integration with existing asset management systems by four steps [45]. He develops an asset classification system and the system supports the exchange of data directly from an IFC into a relational database based on BIM object classification.

f. Kubicki presents a prospective ergonomics methodology for the assessment of synchronous interactive devices dedicated to 3D coordination synchronous and co-located meetings in Virtual Reality (VR) [46]. In New Zealand, Okakpu presents the real benefits of adopting BIM for refurbishment projects to counteract the current reactive traditional measures that are ineffective in reducing the effects of uncertainties that occur in refurbishment projects [47].

g. In Chinese construction industry, there are many challenges to BIM adoption. For instance, in studies conducted by Herr, the applications are assessed during different stages of the design and construction process [48]. He also compares with overseas studies of BIM adoption. The research points out that new regulations, standards and requirements should be introduced.

The above research content studies the application of BIM from different perspectives and purposes, including design optimization, asset management and so on. They provide the basic idea of this research: establishing appropriate specifications, and analyzing the improvement effect of project management quality through practical application based on the BIM applications. The above research mentioned in this section in-depth analysis of BIM application from various perspectives, so that the study can integrate the results of various researchers, and analyze the limitations of current BIM application, and establish the objectives of future research.

5.2.4 Research contribution

There are two achievements in this research, which highlight the novelty

of the study. First, the new workflow combined with BIM applications can enhance the quality of project management in four aspects, including reducing the cost, control the schedule, during the construction period. This is assessed through a case study research, and is novel in terms of optimising the traditional project management workflow. And second, the specifications of modeling mentioned in section 4.4.3 can unify the requirements of information for all participants in the project in order to improve the accuracy of information transportation. This is also assessed as part of project management flow optimisation process, using the BIM application at multiple stages of the project flow.

According to this research, the researcher finds a way to combine the traditional project management process and gradually improves the quality of project management in the BIM application field. The use of case study enables to assess this thoroughly and provide an opportunity to explore the opportunities for BIM application in the project management optimisation. The process proved to be effective in the case study of experiment. Hence, the study offers a novel approach to optimise traditional workflow of project management in the context of China, which can also be adapted to other contexts.

Some limitations of BIM application have been found in this research (mentioned in section 5.2.2). The main problems are the time of modeling making and the training. However, the objectives of future research can be focused on the following factors:

- The families of modeling for standard productions, such as the elements of column, beam, wall.
- Optimizing the software of model.
- Unifying the training course in specifications, workflows.

In this research, the test was carried out in the bidding stage of the new project according to the established specifications and new workflow. In the process of testing, although some difficulties are encountered, the objective is finally achieved. Combining BIM application, applying new

workflow in the bidding work, so that each tenderer can understand the bidding work content more clearly. In pre-contract stage, both the developer and the contractor can describe the project more accurately and reduce the changes in contract management caused by inaccurate information in order to achieve the goal of cost control and schedule control.

5.2.5 Summary

The advantage of BIM application is obviously according to the research, as well as the disadvantage is also clear in contemporary period. The specifications of BIM application and the revised workflow can help the client for enhancing the quality of project management as discussed on above. The technical detail of application such as the regulation of establishing the model, the technic training for the team, the relationship between the model and the contract conditions and so on, must be studied at the next stage.

5.3 Prospects of BIM application from the project findings

Many BIM-focused studies thus adopt a software centric approach that risks overlooking key factors in actual BIM use in practice. [49]

The above research is a preliminary attempt of BIM application based on the perspective of the project management by the client. The specifications of BIM applications are combined with the project workflow. The revised workflows are based on the traditional methods and are generally expected to enhance the quality of project management. During the process of research, the project findings highlight the fact that building information modeling (BIM) can be further studied and applied in the following aspects as demonstrated below.

5.3.1 Concept Design Stage

a. Road show.

   On the basis of conceptual design (graphic, rendering, economic and technical indicators), the information of the estimation and the milestone of the schedule are given and input in the 3D model.

Therefore, the 5D animation can show the virtual construction process to the client for reference. The information would include:

- Cash flow of the project, especially the time schedule of the payment for the general contract and the main subcontracts.
- Schedule. Including the kick-off, foundation, structure, M&E system, curtain wall system, landscaping, and so on.

b. Estimation.

The conventional method of quantity surveyor consultant is used to estimate by indicators (based on the economic and technical indicators in conceptual design). The database of the projects for the client can be updated when the project has completed. Both the professional experience of the consultant and the database of the company can be input to the 3D model, which can be used in the next new project estimation.

5.3.2 Optional Design Analysis

According to request of the different products, the model can be built up in advance, combined with data, such as cost, schedule, purchase, etc. For example, the model comparison is made in aspects of facade and internal decoration, which can provide visualization and data basis for owner's decision and continuously enhance the data and information platform. For example, the project team can make the modeling of different residential layout. The sales team can use virtual reality technology to let potential customers know different types of houses in advance, and determine the scheme with more market demand through investigation. So as to provide reference for design.

5.3.3 Procurement and Tender

a. Build a fitting-out model of residential.

The market request will be the guidance for the project interior design. The model could show the rendering of the residential by visualization and would be the one part of tender documents for the tenders. This would be helpful to the tender having the imagination of the completed product, which can make the tender have the full concept of the

working scope. The quotation of the tender should be more accurate so that the less variation on contract.

b. Specification for BIM.

This research identified the contents of the model. The specifications for the model making shall be created too. As discussed in Chapter 4, the quality of model has effect to the BIM application and the efficient of project management. Therefore, it should be clarified to the tenders not only the specification of contents of BIM (objective, EIR, CDE) but also the requirements of modeler and methods. The contractor should obey the rules and apply the specification for the post contract management.

5.3.4 Construction Stage

Researching the modelling of simulating the construction procedure would be a good training session for the novices. Based on the 3D model, establishing the cash flow mode can accurately reflect the information of the estimation, the project progress, and payment progress and so on. The risk management can be visualized through the information analysis by the model. We can “see” the payment and carry out to avoid overpayment. And at the same time, the negative social effects caused by insufficient payment would be predicted.

According to the experience of project management, the common defect works and safety precautions are set up in the model. The information would be a trigger for the management. For example, it can be informed at the root of the wall about loose concrete caused by insufficient vibration during construction. So that the supervisor could pay attention at this section during the construction period. According to the information management platform, with the view of the quality, security vulnerabilities and hidden dangers, it is directly prompted and handled in the model to form the information automatic record and statistics of quality and security control. In this research, the workflow is expected to be controlled and a complete record will be kept by using the model. Based on this study, the future research can do a good job of pre-control in advance and use

the model to guide the quality control points that should be paid attention to during construction by the contractor.

5.3.5 Objectives of research in the future

a. Facility management

In the research of Vincent J.L., it presents a BIM framework to analyze the effect of natural ventilation on thermal comfort and energy performance in building. [50] It can be seen from his research that in the future, BIM Technology can be applied in the operation and maintenance management and building energy consumption management to enhance the energy efficiency.

The intelligent controlling center would be a 'brain' of the project. The model can show the operation of the system equipment. the management of the operation center can contact the relevant contractors in advance according to this kind of information, and carry out the necessary maintenance work. And at the same time, the center can monitor the operation of all kinds of equipment at any time, notify the management and maintenance worker to arrive at the fault area according to the status shown in the model, and carry out maintenance work in time.

b. Asset management

On the other hand, according to the specifications of ISO19650, the developer can define the contents of asset management. ISO19650 defines the scope of asset management. It includes organizational management, asset and project management, information management in delivery phase and operational phase. It also illustrates the information management process during the delivery phase of assets (W5). For example, the as-build modeling can be delivered by the construction team to the operation department. The later team can input the tenant information in the modeling which is included the rental income, expires and so on. So that the stakeholder can clearly find out the best benefit arears and the type of retail in the modeling. The data will be the guidance for the new mix-used commercial project. In order to ensure the

implementation of these objectives, it is necessary to confirm the delivery team's BIM execution plan, establish the exchange information requirements, establish the task information delivery plans. The information management process must be confirmed at the same time.

What is the better information? How to define the information and requirements of developer? All of these question should be one of the objectives in the future research.

5.4 Concluding remarks

This research study attempts to set up a new workflow for project management with combining the BIM applications and the traditional workflow of project management in the context of China. It also establishes the specifications of modeling for this new workflow through a case study research. This novel approach fulfils the requirements of optimising the project management workflow in the AEC industry, particularly in a context where digital construction is booming rapidly and is in further integration into the practice of project management. This is also tested and assessed with client point of view and how the whole process is optimised for better practicality and applicability of BIM in the practice of project management workflow. The novelty is to understand the traditional workflow, and optimise it through available techniques offered by the BIM application practice. The situation of BIM applications is also introduced and elaborated with the use of a case study, which highlight the overall procedure of such optimisation process. This is important for the AEC industry as shown in the case study review and analysis of Chapter 4, and will certainly add value to the current practices of project management in China.

Based on the standard of BIM applications issued by BSI, this study suggests to create an understandable and implementable set of BIM specifications. It can be involved in the tender documents of new mix-used commercial project. In addition, the revised workflow combined with the BIM applications can be also implemented in the new project, which again highlights the importance and practicality of the optimized PM process – i.e. the project workflow optimization.

For further application of the findings of this study, design optimization and

simulation of construction procedure will also be implemented in the new project as well as the new workflows. The results from this study will be taken forward to practical testing of a pilot project in Shanghai, China. As highlighted from the findings of this study, the main content of future research should potentially focus on the effect of new workflows and their applications in practice. As part of continuing and effectiveness of the project outcomes here, the relevant information will be recorded in detail during the project construction period, and the materials acquired from this research will be utilized to enable this. The content of the record will be compared with the traditional project management model to ensure the new method is fully effective and feasible for the improvement of the quality of project management in terms of the three key aspects of schedule, quality, and cost.

Finally, based on the records of the new project, the role of the new workflow in the quality of project management will be analyzed in future research. The findings from the study will be shared with practices and clients of the new project to ensure they have an overall overview of this new project management workflow and how it is planned from inception to completion. The case of new project will be compared quantitatively with the case of this research in terms of cost and schedule, in order to further optimize the project management process and the specification of BIM application. These will be the next research in future.

References:

Journal articles

[1] Darius Migilinskas, Vladimir Popov, Virgaudas Juocevicius, Leonas Ustinovichius, The Benefits, Obstacles and Problems of Practical BIM Implementation, Procedia Engineering, Volume 57, 2013, Pages 767-774

[2] Ireneusz Czmoch, Adam Pękala, Traditional Design versus BIM Based Design, Procedia Engineering, Volume 91, 2014, Pages 210-215

[3] Hans-Joachim Bargstädt, Challenges of BIM for Construction Site Operations, Procedia Engineering, Volume 117, 2015, Pages 52-59

[4] Michał Juszczyk, Andrzej Tomana, Maja Bartoszek, Current issues of BIM-based design change management,analysis and visualization, Procedia Engineering, Volume 164, 2016, Pages 518-525

[5] Abdulsame Fazli, Sajad Fathi, Mohammad Hadi Enferadi, Mayram Fazli, Behrooz Fathi, Appraising effectiveness of Building Information Management (BIM) in project management, Procedia Technology, Volume 16, 2014, Pages 1116-1125

[6] Tayyab Ahmad, Ajibade Aibinu, Muhammad Jamaluddin Thaheem, BIM-based iterative tool for sustainable building design: A conceptual framework, Procedia Engineering, Volume 180, 2017, Pages 782-792

[7] Vito Getuli, Silvia Mastrolembo Ventura, Pietro Capone, Angelo L. C. Ciribini, BIM-based Code Checking for Construction Health and Safety, Procedia Engineering, Volume 196, 2017, Pages 454-461

[8] The guidance of promoting the application of BIM（《住房城乡建设部关于印发2016－2020年建筑业信息化发展纲要的通知》）

[9] Aleksander K. Nicał, Wojciech Wodyński, Enhancing Facility Management through BIM 6D, Procedia Engineering, Volume 164, 2016, Pages 299-306

[10] Amin Haddadi, Agnar Johansen, Bjørn Andersen, A Conceptual Framework to Enhance Value Creation in Construction Projects, Procedia Computer Science, Volume 100,2016,Pages 565-573

[11] Bac Dao, Sharareh Kermanshachi, Jennifer Shane, Stuart Anderson, Project Complexity Assessment and Management Tool, Procedia Engineering, Volume 145, 2016, Pages 491-496

[12] Zhiliang Ma, Yuan Ren, Integrated Application of BIM and GIS: An Overview, Procedia Engineering, Volume 196, 2017, Pages 1072-1079

[13] Jiang Xu, Research on Application of BIM 5D Technology in Central Grand Project, Procedia Engineering, Volume 174, 2017, Pages 600-610

[14] Varun Maruvanchery, Shao Zhe, Tiong Lee Kong Robert, Early construction cost and time risk assessment and evaluation of large-scale underground cavern construction projects in Singapore, Underground Space, In press, corrected proof, Available online 14 November 2018

[15] Peter Smith, Global Professional Standards for Project Cost Management , Procedia - Social and Behavioral Sciences, Volume 226, 14 July 2016, Pages 124-131

[16] A. Kh. Baiburin, Civil Engineering Quality Assessment in Terms of Construction Safety Index , Procedia Engineering, Volume 206, 2017, Pages 800-806

[17] A. I. Romanova, Improving the Quality of Construction Works in Terms of the Self-regulation, Procedia Engineering, Volume 150, 2016, Pages 2108-2112

[18] Tsegay Gebrehiwet, Hanbin Luo, Analysis of Delay Impact on Construction Project Based on RII and Correlation Coefficient Empirical Study, Procedia Engineering, Volume 196, 2017, Pages 366-374

[19] Nokulunga Mashwama,Clinton Aigbavboa,Didi Thwala, Procedia Engineering,Volume 196, 2017, Pages 447-453

[20] Mccuen, Tl ; Suermann, PC ; Krogulecki, Mj, Evaluating Award-Winning BIM Projects Using the National Building Information Model Standard Capability Maturity Model, Journal Of Management In Engineering, 2012 Apr, Vol.28(2), pp.224-230

[21] Julie Jupp, 4D BIM for Environmental Planning and Management, Procedia Engineering, Volume 180, 2017, Pages 190-201

[22] Christian Nordahl Rolfsen, Christoph Merschbrock, Acceptance of Construction Scheduling Visualizations: Bar-charts, Flowline-charts, Or Perhaps BIM? Procedia Engineering, Volume 164, 2016, Pages 558-566

[23] Danny Murguia, Xavier Brioso, Using “Choosing by Advantages” and 4D Models to Select the Best Construction-Flow Option in a Residential Building, Procedia Engineering, Volume 196, 2017, Pages 470-477

[24] Danny Murguia, Xavier Brioso, Using “Choosing by Advantages” and 4D Models to Select the Best Construction-Flow Option in a Residential Building, Procedia Engineering, Volume 196, 2017, Pages 470-477

[25] Jiang Xu, Research on Application of BIM 5D Technology in Central Grand Project, Procedia Engineering, Volume 174, 2017, Pages 600-610

[26] Manuele Cassano, Marco L. Trani, LOD Standardization for Construction Site

Elements, Procedia Engineering, Volume 196, 2017, Pages 1057-1064
[27] Ghulam Abbas Niazi, Noel Painting, Significant Factors Causing Cost Overruns in the Construction Industry in Afghanistan Procedia Engineering, Volume 182, 2017, Pages 510-517
[28] Renata Schneiderova Heralova, Life Cycle Costing as an Important Contribution to Feasibility Study in Construction Projects, Procedia Engineering, Volume 196, 2017, Pages 565-570
[29] Levente Mályusz, Anita Varga, An Estimation of the Learning Effect on Project Cost Scheduling, Procedia Engineering, Volume 196, 2017, Pages 723-729
[30] Nabil Al-Hazim, Zaydoun Abu Salem, Hesham Ahmad, Delay and Cost Overrun in Infrastructure Projects in Jordan Procedia Engineering, Volume 182, 2017, Pages 18-24
[31] Oluwaseun Sunday Dosumu, Clinton O. Aigbavboa, Impact of Design Errors on Variation Cost of Selected Building Project in Nigeria Procedia Engineering, Volume 196, 2017, Pages 847-856
[32] Xue Li, Jing Xu, Qun Zhang, Research on Construction Schedule Management Based on BIM Technology Procedia Engineering, Volume 174, 2017, Pages 657-667
[33] Christian Nordahl Rolfsen, Christoph Merschbrock, Acceptance of Construction Scheduling Visualizations: Bar-charts, Flowline-charts, Or Perhaps BIM? Procedia Engineering, Volume 164, 2016, Pages 558-566
[34] Turgut Acıkara, Aynur Kazaz, Serdar Ulubeyli, Evaluations of Construction Project Participants' Attitudes toward Quality Management in Turkey, Procedia Engineering, Volume 196, 2017, Pages 203-210
[35] Junying Lou, Jiang Xu, Kun Wang, Study on Construction Quality Control of Urban Complex Project Based on BIM, Procedia Engineering, Volume 174, 2017, Pages 668-676
[36] Vito Getuli, Silvia Mastrolembo Ventura, Pietro Capone, Angelo L. C. Ciribini, BIM-based Code Checking for Construction Health and Safety, Procedia Engineering, Volume 196, 2017, Pages 454-461
[37] GuoHongling, YuYantao, ZhangWeisheng, LiYan, BIM and Safety Rules Based Automated Identification of Unsafe Design Factors in Construction
[38] Georgios Kapogiannis, Mark Gaterell, Eleni Oulasoglou, Identifying Uncertainties Toward Sustainable Projects,Procedia Engineering, Volume 118, 2015, Pages 1077-1085

[39] S. Eleftheriadis, P. Duffour, P. Greening, J. James, D. Mumovic, Investigating relationships between cost and CO2 emissions in reinforced concrete structures using a BIM-based design optimisation approach Energy and Buildings, Volume 166, 1 May 2018, Pages 330-346

[40] S. Eleftheriadis, P. Duffour, D. Mumovic Participatory decision-support model in the context of building structural design embedding BIM with QFD Advanced Engineering Informatics, Volume 38, October 2018, Pages 695-711

[41] F. M. Ugliotti, A. Osello, C. Rizzo, L. Muratore, BIM-based structural survey design Procedia Structural Integrity, Volume 18, 2019, Pages 809-815

[42] Inês Caetano, António Leitão, Integration of an algorithmic BIM approach in a traditional architecture studio, Journal of Computational Design and Engineering, Volume 6, Issue 3, July 2019, Pages 327-336

[43] Vincent J. L. Gan, M. Deng, Y. Tan, W. Chen, Jack C. P. Cheng, BIM-based framework to analyze the effect of natural ventilation on thermal comfort and energy performance in buildingsEnergy Procedia, Volume 158, February 2019, Pages 3319-3324

[44] Martin Röck, Alexander Hollberg, Guillaume Habert, Alexander Passer, LCA and BIM: Integrated Assessment and Visualization of Building Elements' Embodied Impacts for Design Guidance in Early Stages Procedia CIRP, Volume 69, 2018, Pages 218-223

[45] James Heaton, Ajith Kumar Parlikad, Jennifer Schooling, Design and development of BIM models to support operations and maintenance, Computers in Industry, Volume 111, October 2019, Pages 172-186

[46] Sylvain Kubicki, Annie Guerriero, Lou Schwartz, Elie Daher, Bryan Idris, Assessment of synchronous interactive devices for BIM project coordination: Prospective ergonomics approach, Automation in Construction, Volume 101, May 2019, Pages 160-178

[47] Anthony Okakpu, Ali GhaffarianHoseini, John Tookey, Jarrod Haar, Amirhosein Ghaffarian Hoseini, An optimisation process to motivate effective adoption of BIM for refurbishment of complex buildings in New ZealandFrontiers of Architectural Research, Volume 8, Issue 4, December 2019, Pages 646-661

[48] Christiane M. Herr, Thomas Fischer, BIM adoption across the Chinese AEC industries: An extended BIM adoption model Journal of Computational Design and Engineering, Volume 6, Issue 2, April 2019, Pages 173-178

[49] Christiane M. Herr, Thomas Fischer, BIM adoption across the Chinese AEC

industries: An extended BIM adoption model, Journal of Computational Design and Engineering, Volume 6, Issue 2, April 2019, Pages 173-178

[50] Vincent J. L. Gan, M. Deng, Y. Tan, W. Chen, Jack C. P. Cheng,BIM-based framework to analyze the effect of natural ventilation on thermal comfort and energy performance in buildings, Energy Procedia, Volume 158, February 2019, Pages 3319-3324

Books

[B1] Dennis Lock, Project Management (tenth edition), Gower Publishing Limited, Page 1

[B2] Dennis Lock, Project Management (tenth edition), Gower Publishing Limited, Page 2

[B3] K. Pramod Reddy, BIM for building Owners and Developers, John Wiley & Sons, FInc., Page 1

[B4] PAS1192-2 Specification for information management for the capital/delivery phase of construction project using building information modelling

[B5] PAS1192-3 Specification for information management for the operational phase of assets using building information modelling

[B6] PAS1192-6 Specification for collaborative sharing and use of structured health and safety information using BIM

[B7] Standardized Atlas of Safety in Hangzhou Construction Site

[B8] Introduction to BIM (Chongqing University)

Web

[W1] Architecture Science and Technology' (WeChat, 21st Sep, 2017)

[W2] http://classic.sohochina.com/en/about

[W3] bim.construction-manager.co.uk

[W4] http://www.mohurd.gov.cn/

[W5] Wechat/BIM 学习网