A Strategic Decision Making framework for Organisational BIM implementation

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SUMMARY

Decision making during the adoption of Building Information Modelling (BIM) in current AEC projects is believed as a key element to improve both BIM performance and project outcome. In order to provide the most informed decision and strategic plan, two vital elements are required: a comprehensive set of decision making criteria and a reasonable priority system. The literature analysis has revealed that existing assessment frameworks have limitations concerning these two elements. Therefore, this research has been designed to develop a more effective BIM evaluation Framework (BeF), to assist new BIM users and also provide a more effective implementation approach for BIM.

In order to accomplish this objective, research steps of theoretical and empirical nature have been adopted: (a) a multi-dimensional BIM implementation Framework (BiF) was proposed based on the literature review; (b) use of a case study to test the proposed BiF on a real-life project; (c) a questionnaire approach to test the comprehensiveness of the proposed BiF on an industry level; (d) applying the Delphi method to further refine the proposed criteria in a specific context; (e) using the Analytical Hierarchy Process (AHP) to develop a BeF and providing priority shifting for a more preferable strategic goal in Arup ShenZhen office (ASZ); (f) developing a validation system to prove the efficacy of the proposed BeF.

The adoption priority and approach of BIM could be influenced by policies, culture, business structure, legislation etc. As a result, a specific context, China has been selected for this work. The research result could assist decision making in BIM management in the ASZ for a higher BIM performance. The framework by the Delphi method is suitable for the selected context: China. The proposed Delphi and AHP methodological framework can be replicated to assist decision making of BIM management in any AEC organisation.

List of Publications

B Fan, K Chen, H Li & S Wang. 2015. The study of BIM application in China. Journal of Xi'an University of Architecture & Technology. Under Review.

K Chen, H Li. 2015. AHP Based Weighting System for BIM Implementation & Assessment framework. 2015 IEEE International Conference on Industrial Engineering and Engineering Management. Singapore.

K Chen, H Li. 2014. A BIM management model using Delphi approach. European Group for Intelligent Computing in Engineering, Cardiff, UK.

K Chen, H LI, & Y Rezgui. 2013. A BIM Governance Model for UK Construction Project Information Delivery. European Group for Intelligent Computing in Engineering. Vienna, Austria.

Workshop

The 3rd International Workshop: When Social Science Meets BIM and Lean, Chair: Professor Arto Kiviniemi, Keynote speaker: David Philp, January, 2015, Liverpool, UK

Ready for submit

K Chen, H Li. BIM management in the modern construction industry - the implementation & evaluation informed by Delphi method

K Chen, H Li. An analytical hierarchy process (AHP) approach to BIM capability assessment and sensitivity analysis in China

K Chen, H Li. Developing BIM implementation & evaluation framework for China construction project: a mixed of case study, questionnaire, Delphi and AHP approach

K Chen, H Li. The BIM evaluation Framework: evaluation of AEC projects in China AEC industry

Technical report

K Chen, H Li. 2012. Industry Placement Report - BIM Adoption in a Current Construction Design Institute: Shanghai Architecture Institution Xi’an branch.

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Glossary

ABMF	Arup BIM Maturity framework
AEC	Architectural Engineering and Construction
AHP	Analytic Hierarchy Process
BeF	BIM evaluation Framework
BiF	BIM implementation Framework
BIM	Building Information Modelling
BPM	BIM proficiency Matrix
BREEAM	Building Research Establishment Environmental Assessment Methodology
CAD	Computer Aided Design
CIC	Computer Integrated Construction
CIFE	Centre for Integrated Facility Engineering
CR	Consistency Ratio
FM	Facility Management
I-CMM	Interactive Capability Maturity Model
IQR	Interquartile range
IS	Information System
KPI	Key Performance Indicator
LEED	Leadership in Energy & Environmental Design
LOD	Level of Development
MCDM	Multiple Criteria Decision Making
MEP	Mechanical, electrical, and plumbing services
NBS	National BIM Specification
PM	Project Management
ROI	Return on Investment
SME	Small and Medium Entrepreneur
VDC	Virtual Design and Construction

4D BIM	Four Dimensional BIM
5D BIM	Five Dimensional BIM

Chapter 1. Introduction

1.1 Background

The construction industry is seen as one of the most challenging and complex industries in many countries (Mahalingam et al., 2010). The UK government admits that the construction industry is lagging behind other industries in terms of fully utilising digital technology (Cabinet Office, 2011). The reasons are (Porwal and Hewage, 2013, Soares, 2013): (1) the culture in the AEC industry makes it difficult for information to be reused and shared; (2) a majority of the information during the project lifecycle is not re-usable, while poor information management leads to unnecessary duplication of data, project delay and budget overruns; (3) and the entire work flow is fragmented and there is a lack of effective communication between partners. It is difficult to manage change orders, design, cost estimates or planning, and there are big gaps between the design process and the construction activities.

All these lead to low productivity in AEC organisations for a long time. A study by the Centre for Integrated Facility Engineering at Stanford University found that the productivity of the Architecture, Engineering and Construction (AEC) industry has decreased by more than 10% from 1964-2003 (Figure 1-1) (according to the U.S. Department of Commerce, Bureau of Labour statistics). By contrast during the same period, many other sectors have had a dramatic increase in productivity (Adriaanse et al., 2010). One of the main consequences of low productivity is the waste of resources (Eastman et al., 2011, Soares, 2013).

Building Information Modelling (BIM) is a recently emerged digital concept in AEC industry and it is believed that it can help improve productivity as well as have many other benefits (Rezgui and Medjdoub, 2007, Succar, 2009a, Eastman et al., 2011). They work towards a better project performance and outcome (Wang et al., 2015). It has been found that even during the recent economic recession, UK AEC industry is still willing to promote BIM (Cabinet Office, 2011).

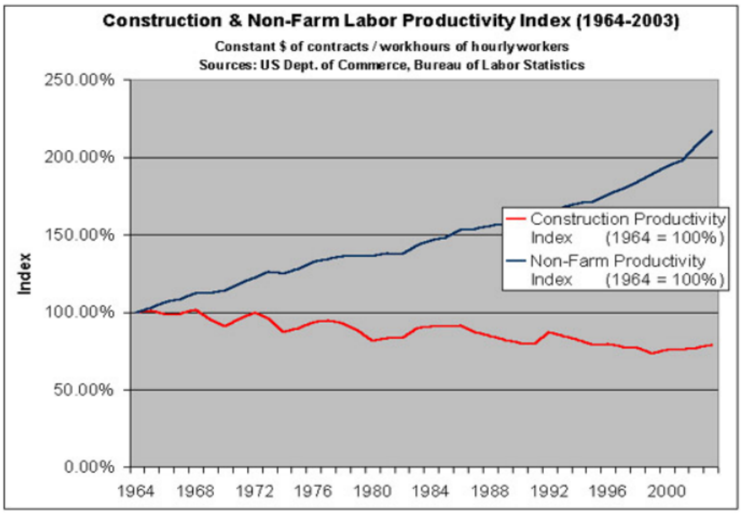

Figure 1-1 Construction & non-Farm Labour Productivity Index (1964-2003)

Source: US Dept. of Commerce, Bureau of Labour Statistics

However, in BIM practice, the transformation from traditional 2D based approach to collaborative BIM, and adherence to legislation (such as building regulations, Environment requirements and local government agencies) in current AEC projects is still low, which is well below the industry's expectation (NBS, 2014, McGraw Hill Construction, 2010).

A survey conducted by the National BIM Specification (NBS) (NBS, 2014) shows the number of BIM users has an increasing rate, which has increased from 13% to 54% (of the total participant) in year 2010 and 2013. Nearly 50% of respondents hold a negative opinion regarding the future of BIM due to: a lack of confidence in their BIM skill; lack of awareness, knowledge and investment priorities on how to meet minimum BIM requirements. Therefore, there are existing overestimation of BIM implementation cost delay and hesitation on the uptake of BIM (Aranda-Mena et al., 2009, Forsythe, 2014, Mom et al., 2014b). A survey conducted by SmartMarket revealed that there are gaps on BIM assessment, functionality selection and client demands for current BIM implementation (McGraw Hill Construction, 2010, Won et al., 2013). BIM was believed to add extra new and complex technologies on top of those already complex and fragmented traditional design and construction process; All these have made practical BIM implementation very difficult and convoluted (Chien et al., 2014).

The integration and merging of the most recognised implementation methodologies could provide a unified awareness, knowledge and understanding among all stakeholders within BIM implementation (Succar, 2009a, Kam et al., 2013a, Forsythe, 2014). These implementation methodologies can also be the key to achieving a more matured BIM standard, and applied by decision makers as a basis to develop a comprehensive BIM execution plan at the commencement of the project (AIA, 2007, Khosrowshahi and Arayici, 2012).

1.2 Research motivation

With the development of BIM, the main focus has been shifted from technology (Brynjolfsson, 1993, Jung and Gibson, 1999) to include management, process, people and policy etc., and that has greatly increased the complexity of BIM implementation process (Succar, 2009a). AEC industry contains multiple activities in various stages and involves participants from different sectors/disciplines (Jung and Gibson, 1999). This partnership could be easily interfered due to different backgrounds, disciplines and geographical locations as well as representing various interests, benefits, risks, competencies, and maturity levels (Gu and London, 2010, Khosrowshahi and Arayici, 2012).

Existing guidelines tailored for different parties, adoption philosophies, technologies required, expected profits, implementation roadmaps and methods of risk management etc. are all different (Gao, 2011, Chien et al., 2014). It is therefore believed that the more parties involved, the wider range of knowledge covered, the more difficult the decision making process will be (Wang et al., 2005). In developing countries e.g. China, after the economic reform, more nationwide partners have been involved in a single project which has greatly increased the complexity of the project, and the difficulty of the evaluation process. BIM users also have a variety of experience, knowledge and understanding in terms of practical BIM implementation which causes different levels of adoption (Eadie et al., 2013). All these lead to an inconsistency of BIM usage level, performance and adoption, even within the same project. Without a unified standard for BIM implementation, diverse of methods, maturity and compliance levels of BIM among project partners will be happened, which can cause interoperability problems (Giel et al., 2012).

Lack of priority leads to high adoption cost

Succar (2010) argues that there is a lack of guidance to prioritise requirements in order to enhance BIM deliverables, this increases risks and budgets during the implementation process (Aranda-Mena et al., 2009, Sebastian and van Berlo, 2010). Porwal and Hewage argues the initial adoption of BIM in a construction project requires significant resources, such as long term training; upgrade of hardware and software license purchases; engineering analysis and simulation activities etc. (Porwal and Hewage, 2013). Moreover, with BIM the AEC industry is now looking for both commercial value and sustainability certification. Due to the lack of adoption priorities, such a full adoption of BIM leads to an early cost increase instead of saving, which causes delay and hesitation of a BIM uptake (Rezgui and Medjdoub, 2007, Won et al., 2013).

The use of BIM in large corporations is also very difficult (Khosrowshahi and Arayici, 2012). While Small and Medium Entrepreneur (SME's) have to be more careful with their resources, large corporations normally have a more matured processes and management approach. The transformation to BIM normally means the change of everything: employees' skill, hardware, software, business process and new services etc. (Khosrowshahi and Arayici, 2012). This leads to a great risk as the actual return on investment could be lower than the expected. Before the actual transformation, a series of complex feasibility studies, Return on Investments (ROI) calculations and business case proposals should be approved by the board of directors. While these efforts only provide an evaluation of an optimised outcome, there are still lack of guidance on how to achieve this, especially in an efficiency way.

Therefore, in order to balance resource and trade-off investment, a unified weightage system is needed (Sebastian and van Berlo, 2010, Jeong et al., 2013). This will assist decision making process of different project parties regardless of their roles and scales, to clarify a unified requirement, target, prioritised key focus area and objectives' which will benefit and assist BIM adoption. This will also reduce its risk and speed up its initial assessment process.

Defects of existing BIM assessment framework

In order to decide what to do or what is the most urgent, the intuition or past experience based implementation approach is not sufficient (Gao, 2011). Bloom and Reenen

(2006) believe improvement in terms of productivity, profitability and business opportunities can be made by assessing and improving the management process, which also improves project performance (Kam et al., 2013a, Miettinen and Paavola, 2014). It is also one of the most effective ways to determine the organisation's real-time performance of BIM, as well as what is to be aligned with the BIM 'vision', use of BIM and to achieve a desired maturity level within the organisation's BIM strategy plan (Sebastian and van Berlo, 2010, Du et al., 2014, PSCIC, 2013, NIBS, 2007b). Barry et al. (2012) believed it is necessary to carry out an initial assessment to identify what are the most needed implementation areas when considering BIM, especially when financial resources are tight. Porwal et al. (2013) also agree assessing the organisation's capability will help new BIM users to get started. Moreover, such an evaluation method is appropriate for individuals (e.g. BIM manager). It is expected to be used prior to the commencement of a AEC project (Wang et al., 2005). Therefore, the strategy for the use of BIM in the project, with goals and paths for a better project outcome, can be developed by the decision maker.

Even though there are a number of BIM evaluation / assessment methods available such as (NIBS, 2007b, Kreider, 2011, Indiana University, 2009b, Duncan and Aldwinckle, 2015) etc., they have not been applied consistently in reality, due to limitations in term of: assessment criteria selection, criteria weightage calculation, assessment coverage, outdated/expandability, validation and impact of criteria towards organisation's goal etc.

Hence, there is a need to develop a more tangible and practical evaluation framework which underlying concept of BIM regardless of the different requirements and types of project etc. most importantly, to consider the objectives of the organisation and which contains all dimensions and factors relevant to a BIM implementation verified by all stakeholders with a consensus (Chen et al., 2014).

Design stage problems and its potential solution

More project pressure and workload has been allocated to the design stage: the richness and accuracy of the nD BIM model is essential during this stage, information relevant to design, fabrication information, erection instruction, project management logistics will be managed through a single database, as a collaboration platform, hence the nD BIM model will be continuously used and developed in the Construction &

Facility Management (FM) stages (McCuen et al., 2012, BSI, 2013, Lu and Olofsson, 2014). It has also been argued that the 3D graphical information of the building will have a great impact on the overall BIM capability which brings a focus on the design phases (Giel et al., 2012). As a result, a certain level of BIM business functions overlap during the design stage and connect with later stages e.g. the application of 4th Dimension BIM (4D BIM) in the construction stage and COBie for the operational stages (BSI, 2014b). To facilitate this procedure of work, all stakeholders are required to get involved at the early design stage to clarify their requirements (Mahalingam et al., 2010, Love et al., 2011). It is also believe, BIM performance and its benefits could be increased if BIM can be used as much as possible, as early as possible by all stakeholders during the BIM procedure (Gao, 2011).

The present author believes that by improving the BIM usage performance during the design stage, there could be a positive influence on BIM's performance in the entire project lifecycle. From this, a BIM evaluation framework that is based on industry practices, mainly focusing on the design phase of a project lifecycle is urgently needed as it could have a positive effect to a company's performance (Miettinen and Paavola, 2014). Such an evaluation framework will have the following features:

1. It addresses those changes that are required to transfer from a traditional approach to a BIM based approach (London et al., 2009).
2. It can also be used to apply self-evaluation for the current status: what is the strength, weakness and what is missing for the actual strategy compared to a targeted level. An improved and customised strategy therefore can be developed;
3. Decision Maker could rely on it to make decisions for BIM adoption;
4. The assessment result could be used by the client during tendering and the prequalification stage by looking for the best match design team.

1.3 Overall Research Methodology

Considering the problem in the current BIM industry as discussed before, a research methodological framework was developed. Firstly, this research proposed a BIM implementation Framework (BiF) that includes five dimensions and sixty nine criteria. In order to test their applicability in the industry, the proposed BiF will be tested on a real project, following a questionnaire to prove the proposed BiF has considered industry perception, awareness and readiness of BIM. It is also necessary to refine these criteria with consideration of industry users' feedback to ensure no missing element remains behind, a consensus based approach: the Delphi method (a multiple rounds of questionnaires approach) was selected to further refine the preliminary framework in a specific context. As for an evaluation framework development, each criteria is required to be allocated with a specific value to represent their weight; should be different from each other. Hence, a group-based decision making method known as the Analytical Hierarchy Process (AHP) method was adopted here as a sensitivity analysis can be carried out to develop new strategic plan (Subramanian and Ramanathan, 2012).

Figure 1-2 overleaf presents an overall flowchart for the work undertaken within this research.

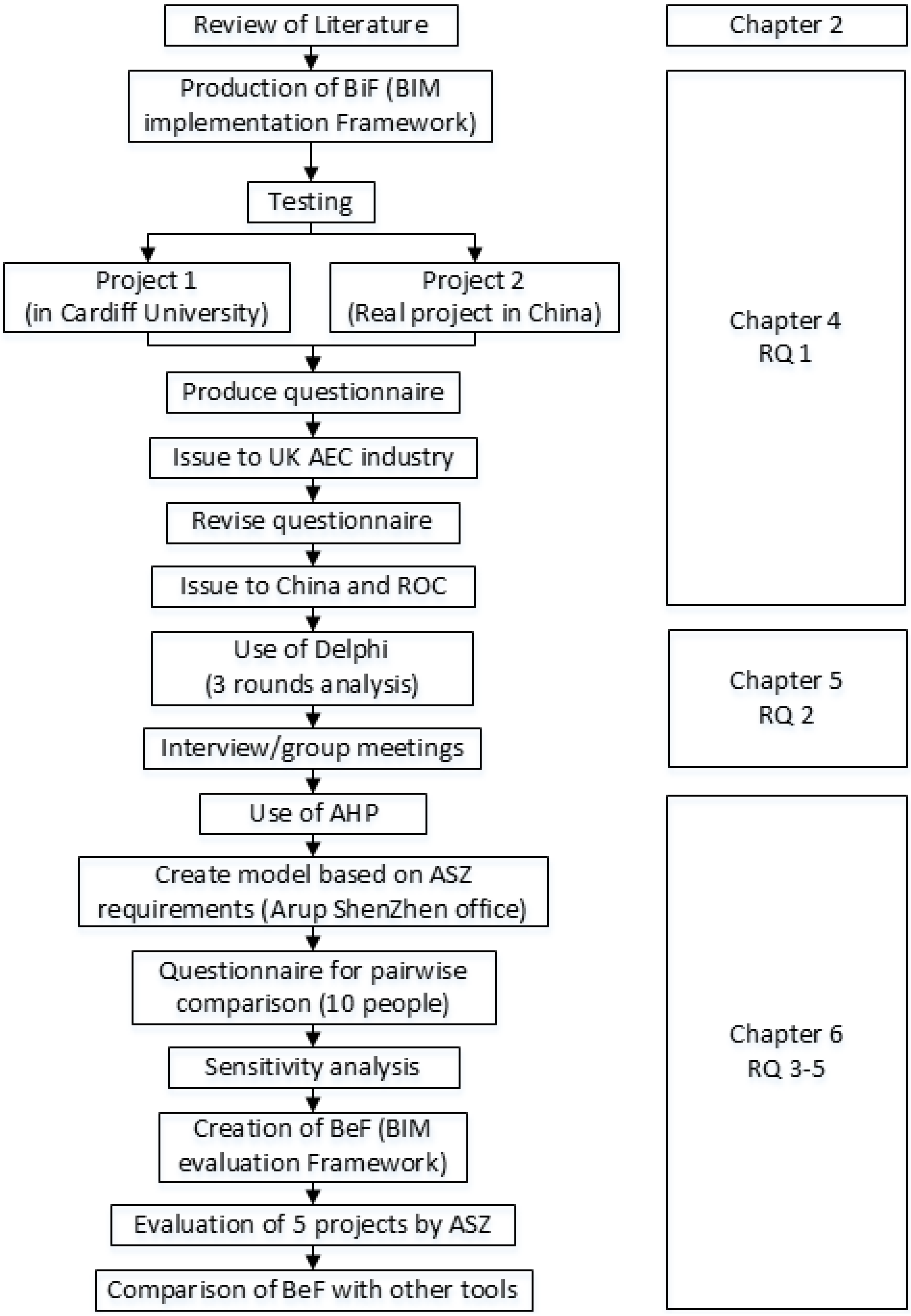

Figure 1-2 Work undertaken in this research

1.4 Research aim and objectives

In summary, this research intends to improve the use of BIM in the AEC projects during its design stage, as well as in the organisational level. The problem statement is formulated as follow: in order to improve BIM adoption efficiency, an evaluation framework is needed to evaluate adoption status of BIM based on a unified prioritised key implementation area. On the basis of the problems and needs mentioned before, this research aims to carry out a mixture of theoretical and empirical studies with the following research objectives:

1. To design a methodological framework to assist the author to develop and validate a BIM usage assessment framework based on both theoretical and empirical data;
2. To develop a multi-dimensional framework that contains key implementation criteria in all aspect of BIM implementation by reviewing current BIM documentation such as standards, guidelines, scientific research, industry practices etc.
3. To test if the proposed framework is functional by using it in an AEC design project case study;
4. To understand the current perception, readiness and awareness of BIM in the current industry;
5. To identify the acceptance and applicability of the proposed framework by achieving a consensus from a panel that includes various levels of BIM users in a specific Chinese context;
6. Based on the context requirement (e.g. Arup ShenZhen office), to derive a hierarchy model from the managerial perspective out of the proposed BiF, to facilitate the priority calculation of all criteria; and also to understand how each factor could influence various objectives of a specific company (positive or negative);
7. To develop a BIM usage assessment framework that can be used in a real case scenario to assess the BIM usage of a project or organisation; used for decision making and self-evaluation purposes;
8. To validate the applicability and effectiveness of the proposed assessment framework.

1.5 Research hypothesis and questions

Based on the previous problems and research aims and objectives, the hypothesis of this research is the following:

'***A BIM evaluation framework including key dimensions and criteria that are relevant to BIM practical deployment during the design stage could help to improve the performance and strategic development for an organisation***'

The authors also argues that developing such tools could shed some light for the management of BIM in developing and developed countries by providing a BIM benchmarking measurement.

Five research questions have been derived to address the research hypothesis:

1. What are those dimensions and factors for BIM implementation and evaluation?

2. What are the most applicable criteria for BIM implementation in the design stage in a specific context, e.g. China?

3. How to develop a multi-criteria decision making tool to assist in strategic BIM implementation and assessment for an organisation?

4. How to validate whether the proposed evaluation framework is practical to use, as well as its efficiency, effectiveness and user satisfaction?

5. How to, by implementing BIM achieve the most preferable strategic goals (e.g. sustainability, customer satisfaction and commercial value) for an organisation through altering their current criteria priorities?

1.6 Scientific contribution

Contribution to existing knowledge in BIM implementation research: This research integrates most BIM standards, guidelines and existing research to come up with a comprehensive list that is relevant to BIM implementation. The prioritising of these criteria reveals the industry's attitude and emphasis in terms of BIM adoption, this facilitates BIM scholars to carry out associated research accordingly, to adapt to the industry's needs, especially for the context of China.

Contribution to existing knowledge in BIM practical usage: This research proposed a BIM evaluation framework. It assesses a project's BIM usage level and exposes the differences between current and targeted levels; it allows self-evaluation to be conducted for improvement; it embeds BIM into the management level decision making process, to have the most appropriate strategy for new objective (focus scheme) preferences; it also allows for a transparent BIM process.

Contribution to BIM assessment in other countries: The methodological framework proposed in this research can be easily replicated to other scenarios e.g.

organisation, country or specific project. By using the initially concluded criteria, simply repeating the Delphi and AHP processes, the particularities of the different context will result easily.

1.7 Thesis outline

The PhD thesis chapters are as follows:

Chapter 1 – Introduction: introduces the problem of BIM in the current industry, the need for assessment and the difficulties in doing so. This chapter also includes objectives, research rationale, research hypothesis and questions, knowledge contribution and thesis structure.

Chapter 2 – Literature review: reviews relevant information to the scope of this research, including: BIM history and current status, BIM implementation frameworks, BIM standards, guidelines and protocols etc. as well as existing BIM assessment frameworks.

Chapter 3 – Research methodology: provides the background on the thesis research paradigm and a general methodological approach. This chapter also reviews, justifies and discusses various aspects of the employed methodology, which combines the questionnaire, case study, Delphi method and Analytic Hierarchy Process (AHP).

Chapter 4 – Dimensions & factors for BIM implementation and evaluation: presents a list of criteria concluded from the majority of existing documentation in BIM. This chapter also presents the results of a feasibility study of proposed criteria through a case study and a questionnaire. This chapter addresses "Research Question 1".

Chapter 5 – Delphi based BIM implementation Framework Refinement*:* the result of the Delphi method will be presented, the primary criteria of BIM assessment framework will be refined through an expert panel and the revised version of the criteria will be determined accordingly. This chapter addresses "Research Question 2".

Chapter 6 – AHP based Strategic Decision Making for Organisational BIM Implementation - presents findings from the AHP expert panel process, which delivers a weightage system to all criteria to support the assessment method. The implementation of this assessment method and its result is also presented in this chapter. In addition, a new set of weightings have been developed to meet the organisation's new focus scheme: sustainability. This Chapter addresses research questions 3, 4 and 5.

Chapter 7 – Discussion - discusses the research findings and limitations of each research step.

Chapter 8 – Conclusion: summarises the entire thesis by providing the answers to the research questions and hypothesis, presenting the contribution to the body of knowledge and future work of this research will also be discussed.

Chapter 2. Literature Review

2.1 BIM introduction

The conventional approach for information management in construction industry could not keep up with expectations for more efficient ways of working due to its limitations and disadvantages (Taylor et al., 2009, Mahalingam et al., 2010). The main aspect missing is the capability of integration of vital information for design evaluation and construction e.g. Bills of Materials, timelines, specifications, price lists, installation and maintenance guide etc. (InfoComm BIM Taskforce, 2011). Moreover, there is a need to share information across all project stages and processes (Rezgui et al., 2013).

The philosophy of BIM was mentioned by Eastman et al. as a 'Building Description System' (Eastman, 1974), and the term 'Building Modelling' was mentioned by Robert Aish in 1986 including 3D modelling, real-time construction simulation (Aish, 1986). 'Building Information Model' was firstly used by Nederveen in 1992 (Nederveen, 1992). The term Building Information Modelling appeared later and was mentioned by Tolman in 1999 (Tolman, 1999).

Initially BIM was defined as a digitalised representation of building and its attributes, a new concept for data, personnel, process and information management (Arayici et al., 2009) during the entire building lifecycle of AEC industry (Eastman et al., 2011, Porwal and Hewage, 2013). It promotes a new relationship and collaboration paradigm among stakeholders. It is also an advanced modelling and simulation concept to improve sustainable design, customer satisfaction and commercial value (Love et al., 2013). In addition, the concept promotes integration, where multiple types of information embedded in the same digital database could benefit and facilitate collaboration among all stakeholders e.g. designer, contractor, facility manager, etc. (Rezgui et al., 2013). More specifically, BIM integrates the following new functionalities into traditional construction process: project feasibility study, 3D design/drawings, atypical shape design, time line management, costing analysis, clash detection, sustainability analysis, constructability, facility management and engineering analysis etc. (Ding et al., 2014, Lee et al., 2015).

The benefits of BIM have been concluded by academics and construction industry. Some of them have been listed as follows:

1. BIM can greatly improve the project performance and outcome (e.g. sustainability, cost and quality) by solving potential problems at early design stage (Love et al., 2013, Miettinen and Paavola, 2014);
2. BIM transforms the project delivery process for improvement and adds value across the whole project lifecycle (Sebastian, 2011, Wang et al., 2015).

BIM aims to provide project stakeholders (the client, etc.) with sufficient information for their better decision makings. More problems can be solved more easily or prevented entirely at an earlier design stage (Napier et al., 2009).

BIM has already been adopted by countries such as US, Finland, Denmark, Norway etc. and have made considerable progress (Arayici et al., 2009, Smith, 2014). UK released government's strategy in 2011 to introduce the push-pull approach for BIM implementation for all government project with an aim of achieving 20% saving during procurement cost (BIMIWG, 2011, Cabinet Office, 2011). 'Push' aims to improve the construction benefit from the industry side by requiring all users to reach BIM level 2 (fully collaborative 3D BIM, where all project and asset information, documentation and data being electronically managed) (Figure 2-2 below) by 2016. Relevant 'push' elements include guidelines, training and tools. 'Pull' from the client side aims to improve the post - occupation benefit, where information will be specified, collected and used by the client (Churcher and Richards, 2013). This will require the specific information need to be prepared and delivered to the client on time.

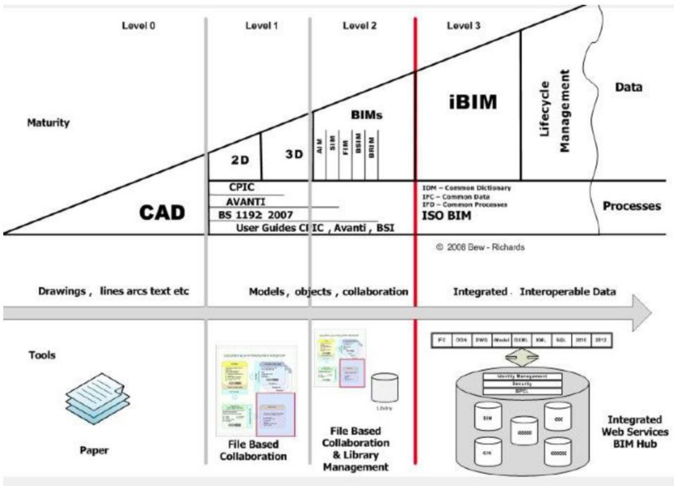

Figure 2-1 BIM maturity levels by Bew –Richards (BIMIWG, 2011)

China BIM Union was established in 2013 as part of the China Industry Technology Innovation Strategic Alliance by the Ministry of Science and Technology. It initiates the development of China's own construction information standards and relevant building information standards (MCIWLG, 2003, MOHURD and AQSIQ, MOHURD, 2014), since it is believed as the key for BIM to be continuously improved in a positive way, projects over 20,000 square meters need to include BIM procedures (MOHURD, 2013). Various standards, guidelines (e.g. Beijing (BMCUP, 2013)) and initiatives for BIM have also been developed in some of the more developed areas in China (e.g. Shanghai (GOSMPG, 2015) and Guangdong (DHURDGP, 2014) etc.). Such standards and initiatives are still at a very basic level, only including IT requirements, level of development (LOD) and data delivery. The official document for BIM strategy of China was released in 2015, with the following requirements imposed by the government: first class design organisations and first class contractors should be able to integrate BIM with their organisational management system and other information technologies by 2020; more than 90% of the future government owned projects regarding design, construction and operation should be BIM compatible by 2020 (MOHURD, 2015).

In summary, BIM covers the whole life of a construction project (Taylor et al., 2009). However, technical aspect development at the design stage brings more tangible profits to users compared to those at later stages. This caused an increased interest in the technical side of things and a reduced one concerning the non-technology aspects of BIM, such as the development of BIM lifecycle (Jung and Gibson, 1999). This therefore leads to a main focus on specific BIM technical applications e.g. visualisation, scheduling management, clash detection etc. However, due to the lack of effective guidance, the coordination and management paradigm is still technology driven or even based on traditional approach (Gao et al., 2015). This is not in line with the industry's expectations (NBS, 2014, McGraw Hill Construction, 2010).

2.2 BIM dimensions

With the wide adoption of BIM in the worldwide AEC industry, new areas of BIM implementation and new business opportunities are being explored. The main implementation focus has been shifted from technical only to multi-dimensional aspects e.g. management, process, people, policy etc. (Brynjolfsson, 1993, Jung and Gibson, 1999, Succar, 2009b, Succar and Kassem, 2015). This has greatly expanded the implementation area and also the complexity of the implementation process (Popov et al., 2010).

Technology

Technology has been defined as 'the application of scientific knowledge for practical purposes' (Dixtionaries). BIM can be regarded as an extension of the conventional CAD approach (Singh et al., 2011). As mentioned, a starting point, the focus was laid on the relevant technology improvement which is believed to be the key to speed up the transformation process (Gu and London, 2010). However, such implementation paradigm neglects other non-technological aspects, their roles and functions, which has resulted in a negative effect (e.g. messy talking (Ibrahim, 2013)) and hindered long term development that is required for optimum BIM implementation (Khosrowshahi and Arayici, 2012, NBS, 2014).

Management

The managerial aspects also play a key role as it improves the viability, efficiency and effectiveness of BIM by providing strategic planning, which will also assist decision making as well as prioritise actions (Jung and Gibson, 1999, Tsai et al., 2014). The key business indicators that have been identified by Aranda-Mena et al. (2009) also proved the value of adopting BIM from management perspective.

Process

Process has been defined as 'a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action' (Davenport, 1992). With the adoption and evolving of BIM, the process of traditional AEC project: its components and relationships between project stages, activities and tasks within each stage, have all been influenced, which include business drivers, automated process analysis and interoperable information that is consistently used throughout the project lifecycle (Succar, 2009a). Recent empirical study even proves that process aspect have a larger proportion than technical aspect (Eadie et al., 2013).

People

People as the instigator and primary medium of revolution, especially their new roles and responsibilities receive equally important attention and function during BIM implementation (Howard and Björk, 2008, Gu and London, 2010). A good leader should be able to inspire the participants of a fragmented and complex project structure, and push towards a common goal for the project, or even for the organisation. Hence to improve collaboration, and solve problems among partners (Dossick et al., 2010).

Policy

Policy is described as 'written principles or rules to guide decision-making' (Definition of Policy, 2007). This will include practitioner preparation, problem research & solution, benefit & risk allocation and collaboration among stakeholders etc. Factors contained in this dimension include: contractual and legal standard, regulations and research and development etc. (Succar, 2009a).

2.3 BIM implementation

Lee (2007) proposed four phases of BIM implementation in practice:

1. Phase one: personal adoption – BIM data produced by a single modeller for his own discipline;
2. Phase two: the adoption of BIM in a single discipline within the organisation;
3. Phase three: the adoption of BIM in multiple disciplines within the organisation;

4. Phase four: the adoption of BIM across organisations and different platforms.

The organisation is an integration of individuals (Khosrowshahi and Arayici, 2012). Since the main challenges of adopting BIM is the organisation's readiness to change, the willingness from the employee is believed as the main roadblock for BIM using in organisation (Dossick et al., 2010, Lee et al., 2015). Moreover, there is also a strong correlation between an individual's BIM skill and the BIM capability of their company (Giel et al., 2012). In order to improve people's willingness to change, their awareness and confidence regarding BIM effectiveness compared to ordinary business activities need to be improved (Singh et al., 2011). Arayici and Coates (2013) emphasise that by focusing on the technical training (e.g. operational skills) of individuals on a daily basis, the benefits of BIM would become more apparent, which will further improve people's confidence in BIM.

Nonetheless, adopting BIM around the traditional process is a 'major change management task' (Khosrowshahi and Arayici, 2012). The main issue for BIM adoption to the next level is the lack of a well-developed strategy to improve the collaboration between disciplines and organisations on an industry wide level, which could maximise the benefit of BIM as well as facilitating innovation (Teicholz, 2013).

Recent efforts have been proposed to improve BIM adoption in the AEC industry from different perspectives. This includes the development of BIM implementation frameworks by researchers, and associated BIM implementation guidelines, standards, execution plans and protocols by government or research institutions.

2.3.1 BIM standards, guidelines, executions plans and protocols etc.

The government is believed as the most effective leading force to push BIM adoption (Cabinet Office, 2011). Meanwhile, national or international research organisations such as NIBS, AIA, buildingSMART, BSi have investigated methodologies to refine the BIM deployment approach from their own perspective (Arayici et al., 2009, Miettinen and Paavola, 2014). Existing BIM documents (e.g. standards, guidelines and protocols) are available for BIM users to implement BIM into their system (Tsai et al., 2014a). The selection of method according to the user's interest and preference leads to competition and development (Miettinen and Paavola, 2014). The continuous publishing of BIM standards has resulted in '*simultaneously development of standard* *procedures and tools and their constant reconfiguration locally'* (Suchman, 2007). Such a plethora of BIM documents could potentially lead to diverse methods, maturity and compliance levels of BIM among project partners, which can cause interoperability problems.

A **BIM Execution plan** e.g. (Penn State University, 2010) reflects the practical implementation of BIM guidelines. It listed those key BIM implementation areas along with who will responsible for each activity, as well as when it will be delivered in an actual project. It intends to achieve an agreement on the plan of the BIM strategy among project partners at the early stage of the project, including BIM users, roles and responsibilities of each individual, deliverables, legal issues, liability and responsibilities and other key points for BIM to be highlighted to all parties throughout the whole project (NIBS, 2015).

By adopting a BIM execution plan, a transparent liability and responsibility among project participants can be established, and therefore reduce potential disputes and improve the collaboration process of the BIM based environment.

In order to align BIM concepts to the contract, BIM guidelines and standards and execution plans can be transferred into a protocol format which will then be endorsed by all partners. Such protocols can provide a general requirement at each stage of work regarding to the deliverables, and ensures all individuals to work in a well-co-ordinated environment. It also serves as a foundation for BIM to be adopted in a project by providing the structure and support to the company's own guidelines and standards (State of Ohio, 2010).

Regarding the massive amount of documents available in the industry, only a few have been discussed in this research. In order to provide a general idea of what those key implementation areas are or areas that need special attention, the selected documents have been only reviewed generally without detail. For example, one of the guidelines that suitable for both new and renovation projects, the project: BIM Requirements by Senate Properties of Finland (Senate Properties, 2007) identifies the criteria that affect decision making during the modelling purpose of the entire design process, such as design alternative comparison (scopes, costs and energy budget etc.), modelling element explanation of each discipline (e.g. architectural, MEP and structural BIM), quality assurance.

For more explanation on the documents explanation and their coverage comparison please refer to Appendix A.

BIM guidelines for different sectors

Other than the above mentioned standards and guidelines for BIM implementation from a lifecycle and all disciplines' perspective, there are also documents that have a focus on a certain discipline's perspective e.g. client and contractor.

Client perspective

Dawood & Iqbal (2010) believes architects are in the position to lead the BIM implementation in order to support the integrated project delivery through control, coordination and management of the project. For the architectural discipline, BIM is more like a digitalised modelling process technology which assists in meeting the client's requirements (TAGCA, 2006, NYCDB, 2013, BSI, 2014a). Regular data drop to the client could keep the client up to date with the latest progress, thus making them aware of design performance, to minimise change order at later stages. Moreover, this could also incrementally improve the client's understanding of the design scheme (BSI, 2014a). The client therefore should be responsible for the additional deliverables and services e.g. as-built models (TAGCA, 2006). Moreover, considering the availability of integrated single database and engineering analysis functions, in a BIM based environment, the client can now procure documentation for performance in energy savings and carbon reduction on top of the usual documents provided by a traditional approach (SECG, 2013).

Contractor perspective

In order to help the contractor to start using BIM, relevant documents have been reviewed (TAGCA, 2006, SECG, 2013): The contractor could adopt BIM from four aspects: tools, process, responsibilities and risk management. The selection of BIM tools should be based on multiple criteria, such as cost, expected functionalities, training and compatibility with the industry trend. Based on the BIM tools, the BIM process should be tailored to produce the expected outcome. BIM could change the way in which people collaborate, share project data and review relevant work. The core of each partners' responsibilities will not be changed but new roles will be allocated to redefine and clarify the new responsibilities among the project teams.

Moreover, with regards to the characteristics of BIM: the sharable digitalised collaborative database that to be used and exchanged among all project participants, their ownerships and liabilities are evolving along with the project progress. Hence risk management is another issue need to be considered. For contractor, 'what are the deliverables and who is responsible for them?' are the most important questions.

The review of existing BIM documents (guidelines etc.) has concluded some findings shown as follows:

1. The implementation area for BIM in different disciplines, sectors and project stages have a similar content and coverage;

2. Most information used during construction and later operation stage are based on the BIM database or 2D drawings created in design process, therefore all later applications of BIM are dependent on the design outcome. As a result, clients and contractors are required to participate in an earlier design stage to clarify their demand of what kind of information is to be embedded within the design model.

However, some disadvantages of surveyed documents (guidelines etc.) have been identified in practical usage:

1. Existing guidelines etc. have been developed based on the local workflow, supply chain readiness, infrastructure etc. which may not be suitable to other regions;
2. Key implementation areas have merely proposed, without thorough priority or adoption sequences according to a specific project's requirements; they are sometimes based on intuition. This type of adoption could lead to budget overrun loss of focus. What's more, a more effective strategy plan to meet business objectives is needed (Tsai et al., 2014a);
3. Different sectors/disciplines will have their own focuses, this could lead to a different prioritising sequence in term of BIM adoption;
4. The project outcomes, limitations and drawbacks of the implementation process for using existing guidelines cannot be evaluated (Kam et al., 2013a, Tsai et al., 2014a).

2.3.2 BIM Implementation Framework

A framework represents a holistic relationship of terms and concepts of a system (Jung and Gibson, 1999). It aims to sort out the logic structure of the interested system as well as the future development direction (Jung and Joo, 2011). Similar to the framework, the model can be defined as the representation of a reality in a specific environment (Dehe and Bamford, 2015). By developing such a framework for BIM, it will facilitate all practitioners to be fully aware of the composition of the BIM concept. By considering BIM as the integration of final product and the process of delivering it, users will begin to understand, disseminate and incrementally implement BIM. In addition, a framework that could achieve 'presenting data and arguments in manageable sections' could fulfil the gap remains between academic and industry knowledge bodies (Succar, 2009a). A number of BIM collaboration frameworks have been briefly introduced in the following sections.

Information System (IS) is one predecessor that is similar to the concept of BIM, which is believed to improve the effectiveness of AEC projects. However, the concept of IS lacks a clear strategy with focus and objective. The strategy and IS could complement each other: the strategy could serve as a clear future direction and development guidelines for IS, while IS could explore more and more business opportunities and market which influence the organisation's strategy. CIC calls for the integration between IS and the AEC industry to improve its productivity. However, this undertaking emphasises only the technical aspects. The industry and practitioners therefore lack knowledge on how to implement CIC, to what extent it should be developed and what is the prioritising sequence of demands (Jung and Gibson, 1999).

Therefore Jung and Gibson (1999) proposed a planning methodology for CIC implementation from company level. The CIC framework includes three dimensions: Information System (IS) Concern (4 areas of concern), Business function (14 functions) and project lifecycle phases (6 phases). In order to provide an objective and quantitative assessment result, five main areas for the assessment have been proposed: corporate strategy, management, computer system, IT and incremental assessment, these five areas include both business and social-organisational issue. Moreover, business functions have been considered as evaluation criteria for effective CIC planning. Analytical Hierarchy Process (AHP) was proposed by the authors to assign relevant weight to those measures in future work. The individual assessment of these five main areas could effectively assist decision making during implementation in their own domain, and together as a whole. Instead of making a decision, they could also balance resource investment on an organisational level, identify their departure point and objectives. However, in this research, Jung et al. have not considered cross organisation collaboration or data management issues. Based on the connection between BIM and CIC, as a follow-up study of (Jung and Gibson, 1999), Jung and Joo (2011) proposed a framework to systematically represent relevant areas of BIM practical implementation. The thesis author argues, before the development of an assessment framework, these assessment criteria should be validated for their applicability by industry practitioners. The proposed framework is not comprehensive enough either. One limitation for example is that degree of involvement of all partners during BIM implementation should be considered. Moreover, the framework requires an update under the 'function' category as follows: business function during the operation stage should be considered, since the information required for building operation purpose should be prepared in early design stages. Most importantly, there is no follow up research to develop an evaluation methodology based on Jung's framework.

The approach mentioned above has been summarised as top-down pattern for CIC implementation. Top-down pattern intends to curtail the adoption of CIC by partially select adoption scope according to the priority of managerial prioritise and organisation's strategy. This will have a more effective outcome compared to a full-range adoption. Based on the identified limitations of CIC and IS, the key of BIM success is to have a tangible and practical BIM strategy and prioritised key implementation criteria across all aspects (PSCIC, 2013).

The top-down approach could also be aligned with the 'touch the BIM lightly' approach: a relatively more progressive and acceptable paradigm for technology proficiency, which resulting in a more focused and effective learning process (Ibrahim, 2013, Forsythe, 2014). Hartmann et al. (2012) also agrees that a top-down approach could effectively integrate BIM with the organisation's strategy and could strategically plan for BIM as a goal for large scale and long term implementation (Arayici et al., 2011). Dikmen et al. (2005) revealed that organisation strategies are one of the main driving forces for achieving organisational effectiveness.

Khosrowshahi et al. (2012) believed that to implement a new concept like BIM, it is important to identify the core of the problem, the current status of existing approaches as well as an example to follow. The culture, personnel and technologies of organisations are different, which require a specific strategy for a better implementation. The author conducted a mixed of qualitative and quantitative method to identify the industry's readiness. First, a literature review was employed to reveal the current practice of BIM, include both driving forces and barriers of adoption. Secondly, a BIM implementation concept map was developed based on the interview with BIM users in Finland. Khosrowshahi et al. argues this map is believed to be a reference object for UK BIM implementation. It includes three focus points: organisational culture, education and training and information management. Thirdly, a questionnaire approach was adopted in UK AEC industry to identify people's perception and level of acceptance for BIM in UK's AEC industry. The questionnaire's result could derive another concept map specific for UK's status. Lastly, a road map based on the results from the three research steps has been developed: provide a feasible implementation strategy and guidelines as well as find answer for breaching the barriers and challenges which came to light during the questionnaire.

There are some defects of the above mentioned research. The roadmap summarised from interview session contains a number of criteria. The importance level of these criteria have not been assessed by all interviewees to check their consensus, since some of these factors might disagree with others. Khosrowshahi and Arayici (2013) claim the final road map which provide a list of 'implementation areas' could allocate limited resources in a better way. However, without prioritising this list, it will be hard to decide what is more important and what needs to be done first. This could lead to waste of resources, or even confusion on where to start, hence the effect will be limited. Moreover, the author fail to assess if what have been summarised from Finland is adopted in UK due to the differences between these two countries, such as culture, policy, infrastructure etc.

Please refer to Appendix B for more existing BIM implementation frameworks that have been reviewed.

2.4 BIM Assessment and Benchmarking

2.4.1 BIM Evaluation & assessment

Kwak and Ibbs (2002) proposed an idea to assess project management, they define a good project management (PM) as ‘a well-defined level of sophistication that assess an organisation’s current project management practices and processes’. They also believed that the composition of assessment approach used to assess organisation’s current practice has become sophisticated over the years. It therefore leads to confusion, uncertainty and difficulties in assessing their current practices. Hence a $(PM)^2$ model was developed as a reference point and yardstick to identify the current status and weakness of PM practice within the organisation. In addition, it also acts as a systematic and incremental approach, which guides project managers to transit from unsophisticated to sophisticated levels.

The development of assessment method in BIM is lagging behind than other domain in the AEC industry (Kam et al., 2013a). For example, for green building evaluation/assessment, there are a number of environment assessment framework available on the market, for example, BREEAM, LEED etc. These methods are generally divided into three parts: the first part introduces the goal of the assessment, followed by the second part, categories of concern; the last part deals with the assessment criteria in each of the described categories (Chang et al., 2007b).

I-CMM BIM assessment framework:

As the earliest and most used assessment framework in the US, the National Institute of Building Science proposed the BIM Interactive Capability Maturity Model (I-CMM) based on 11 criteria (data richness and information accuracy etc.) with 10 capability maturity levels for each. It intends for ‘users to evaluate their business practices along a continuum or spectrum of desired technical level functionality’ as well as ‘for use in measuring the degree to which a building information model implements a mature BIM Standard’. Regarding its single aspect of assessment in information management, it is not for any benchmarking purpose or for ‘BIM implementations comparison’ (NIBS, 2007b, Kam et al., 2013a).

The evaluation result can be affected by many variables which could potentially reduce the effectiveness of the assessment method (Succar, 2009b). Firstly, the weighting scheme for the maturity level of each criteria can be modified freely by the user (NIBS, 2007b, Succar, 2009b). However, there is no scientific calculation method to provide the most reasonable weighting system; as a fact, the weight was obtained by vote (McCuen et al., 2012). Secondly, the lowest credit required to meet the 'minimum BIM' will change with time: 'as the rhetorical bar is raised and owners demand more from the models being delivered' (NIBS, 2007b). On the other hand, the accumulative credit gained from the I-CMM is not reliable, since a higher result does not guarantee every aspect of the evaluation could achieve the associated maturity level. There are ten maturity levels for each of those evaluation criteria, while normal assessment methods will have a maximum of five to six maturity levels (Succar, 2009b). This could confuse the assessor during maturity level selection. These ten criteria have not been explained well for practical usage, and there is also a definition overlap, in some cases (Suermann et al., 2008).

The I-CMM has been adopted to assess the AIA-TAP BIM Award winners in both 2007 and 2008 (Suermann et al., 2008, McCuen et al., 2012). However, only visualisation aspect has been tested, while the accuracy of other areas of BIM adoption have not been tested.

BIM proficiency Matrix (BPM):

In order to evaluate the individual's BIM skill proficiency, for both designers and contractors (Kam et al., 2013a, Giel, 2014), Indiana University developed a BIM proficiency Matrix (BPM) with eight categories and each category has been divided into four maturity levels (Indiana University, 2009b). A score is also presented with associated certifications. From the present author's view, there is not enough information available for research purposes or validation processes to test its validity. Kam believe this assessment method lacks social aspect consideration (Kam et al., 2013a).

BIM3 – Succar BIM assessment framework:

Succar (2009a) divides the BIM field into three parts: technology, process and policy; each dimension includes both players and deliverables. A push-pull relationship will be formed between any two parts so as to deliver the required information or business activities e.g. contractual relationships and project deliverables. Succar also defines BIM stages into four, starting from non - BIM to the current ultimate BIM level:

integrated BIM. It expresses a gradually and continuously implementation maturity of BIM stages in term of process, technology and policy.

Based on this framework, Succar (2009b) developed a BIM Maturity Matrix (BIm^3) as ‘a knowledge tool which incorporates many BIM Framework components for the purpose of performance measurement and improvement’. BIm^3 contains five components (Succar et al., 2012):

1. BIM capability stages: ‘is defined here as the basic ability to perform a task or deliver a BIM service/product’;
2. BIM maturity index: ‘to reflect the specifics of BIM capability, implementation requirements, performance targets and quality management.’
3. BIM competency sets: ‘reflects a generic set of abilities suitable for implementing as well as assessing BIM capability and/or maturity.’ In more detail, it can be classified into three groups: technology, process and policy to align them with the BIM field (Succar, 2009a);
4. Organisational hierarchy and scale, ‘To allow BIM performance assessments to respect the diversity of markets, disciplines and company sizes’;
5. BIM granularity levels to increase ‘assessment breadth, scoring detail, formality and assessor specialization’ along with the increase in granularity. In total, they have included area such as: software, hardware, products & services, contractual and organisations etc. (granularity level 1).

However, there are still defects to be addressed further by the present author.

Firstly, only three dimensions: policy, process and technology are included. Each dimension has stakeholders, such as regulatory bodies in policy dimension, owners and designers in process field and software companies in the technology dimension. With the consideration of multiple dimensions of BIM, as well as the equally important levels of these dimensions, there is a need to re-categorise some factors within these three dimension (e.g. people) into separate dimensions (e.g. people dimension), to form a clearer pull-push relationship under BIM interactions and BIM field overlaps.

Secondly, the assessor needs to select the scale of their organisation as well as their benchmarked granularity level ‘to enhance BIM capability and maturity assessments process and to increase their flexibility’ (Succar et al., 2012). Compared to less granularity, the selection of higher granularity will have more assessment criteria to be used. Succar argues this could be suitable for various purposes and different kinds of assessments. Informal/self-assessment will prefer a more abstract level of assessment, while 'specialist-led appraisals' could prefer a more detailed assessment.

Thirdly, the number of 'competency areas' can also be influenced and varied by the organisational scale and capability stage (Succar, 2009b). However, the author of this thesis argues this type of 'flexibility' might cause inconvenience and inaccuracies during the assessment as the actual 'competency area' of BIM is unpredictable in actual practice. For example, an organisation's major BIM 'competency area' is in stage 1, however, they may have met the standards of some assessment criteria that belonged to higher granularity level, such as stage 2 or even stage 3. In this case, the selection of stage 1 could not provide an accurate result.

Lastly, Succar only published those 'competency area' for granularity level 2 (Succar, 2009b) and 'competency area' for technology dimension for level 4 (Succar et al., 2012). Moreover, the BIM maturity matrix is only based on granularity level 1 (Succar, 2009b), hence there is a lack of comprehensive explanation for overall assessment criteria. Sebastian and Berlo (2010) comment that once the minimum requirement of capability in a granularity level has been reached, there will be no further comparison until the next stage of maturity matrix has been used and achieved. Sebastian and Berlo also argue the proposed framework could not compare the experience and modelling quality of BIM in different organisations, even they are at the same stage. Kam et al. (2013a) also comments there lacks of validation of the proposed framework.

<u>BIM Characterisation Framework (Gao, 2011):</u>

Gao (2011) proposed a characterisation framework for BIM, with the intention to understand how BIM should be conducted and who should be involved. This framework has divided BIM based project information into 3 categories, 14 factors and 74 measures.

Gao argues the adoption of BIM in a single case study is inconsistency and insufficiency. It requires data to be collected from large amount of case studies. Data from 40 case studies have been collected and analysed to finalise a comprehensive list of criteria which can be used as benchmarking by other users to compare their work with best practices. New 'implementation criteria' could be identified and added into existing framework. It could also be repetitively used by the same organisation, with experience accumulated, to reveal the most often used criteria as top priority; a template of BIM adoption can be developed for future use.

According to the present author, this research also has its limitations though: (1). The criteria within the framework needs to be updated e.g. 5D costing control has not been considered; (2). The framework is only applicable for BIM implementation process on project level, not organisational level; (3). It targets at design and construction stage, while the information required by operational stage should be considered as well in early design stage; (4). The collected user perceptions on BIM performance are not for evaluation purpose. (5). The proposed framework has only been tested using already completed projects. Its value and benefit on new projects has not been tested.

Organisational BIM assessment framework (Kreider 2011):

With the emphasis on the top-down BIM implementation paradigm from the management level (Jung and Joo, 2011), the use of BIM within the organisational level received a higher emphasis from BIM users. A BIM maturity framework from client/facility owner's perspective was developed by Kreider (2011) for organisational BIM (OBIM) usage. This assessment framework contains six main areas: strategy, uses, process, information, infrastructure and personnel's BIM competency. This assessment method is believed as effective (PSCIC, 2013). However, the present author believes the result provided could be inaccurate, as it assigns equal weights to each maturity level and each criteria, and that will not be able to identify the priority of assessment criteria. Besides, the method also lacks relevant assessment in data management, BIM application and stakeholders' involvement. Finally, how those criteria have been selected and whether they are empirically validated or not is unknown.

ABMF Maturity framework from Arup

Andrew Duncan and Graham Aldwinckle from Arup proposed their own BIM project Maturity framework (ABMF) to assess project management aspect within four primary disciplines: SMEP (Structural, Mechanical, Electrical and Public health) and 21 secondary disciplines (Acoustics and Fire etc.) (Duncan and Aldwinckle, 2015). There are 11 questions (Common Data Environment and reference/version control etc.) and 3-6 maturity levels for assessors to select for project management, and 12 criteria (e.g. LOD, 4D and 5D etc.) for other primary and secondary disciplines. In these 12 evaluation criteria, one criterion is discipline specific, the rest remain the same.

The ABME framework was mainly designed to assess BIM process based on the work done by Penn State University. Those assessment criteria are in majority for design related disciplines, which might not be applicable to other secondary disciplines e.g. public health.

Arup intends to use ABMF to compare their own worldwide BIM projects. According to the present author, the selected criteria and weight can be influenced by the local cultural and government policy in company level. While there is a lack of relevant information on how those criteria have been created or selected, their applicability towards users from different regions has not been described, and no empirical evidence could show the reliability of the assessment result. Additionally, how the weight of each criteria was obtained has not been explained.

2.4.2 BIM Project Benchmarking

Benchmarking is a structured method to measure and compare an organisation's processes, activities, and performance against others organisations (Garvin, 1993). By comparing with other peers' best practice, it could reveal the defects of current practice and an appropriate improvement strategy can be planned and proposed accordingly (Camp, 1995, Succar and Kassem, 2015). The benchmarking process will gather a group of decision makers from different organisations, who will share knowledge and experience amongst themselves to encourage innovation (Garvin, 1993, Costa et al., 2006). The result achieved can be used to rank the organisations' competitive position within the industry level and the organisations' possibility of success (Tsai et al., 2014a).

However, most existing assessment framework are only suitable for evaluation but not for benchmarking, and there is no available national or international BIM benchmarking instrument existing yet (Sebastian and van Berlo, 2010, Du et al., 2014).

Sebastian and Berlo (2010) proposed a BIM benchmarking tool including 4 main perspectives: organisation and management, mentality and culture, information structure and information flow, tools and applications. These perspectives have been further divided into following factors: vision, roles and organisation structure etc.

Interviews and desk research have been used to formalise the framework. According to the present author, there are some limitations for that framework:

1. During the first research step, desk research might intake some criteria which haven't been reviewed during the interview session, which need further validation;
2. The use of this benchmarking tool requires certified professional users, which will hinder the dissemination industry wide;
3. As a benchmarking tool, Sebastian and Berlo fail to address how the selection of assessment criteria and their weightage calculation could meet the requirements, visions, strategies and implementation focus of different organisations;
4. The accuracy of the proposed tool has not been proved. The validation process includes two organisations, the author only mention 80% of assessment criteria received a consistent result for the fictional organisation, but do not mention any result for the real organisation.

CIFE developed Virtual Design and Construction (VDC) maturity evaluation scheme focusing on four areas: planning, adoption, technology and performance, which aims to provide quantifiable and qualitative measures. It uses scorecard to evaluate its market, performance, barriers and future development direction. The method can also be used for BM assessment (Kam et al., 2013a).

The assessment framework has been further divided into 10 subdivisions (e.g. objective, organisation and process etc.) and 56 measure items. In order to enhance the reliability of the result, confidence level with seven factors have been adopted to assess the accuracy of the information of an assessed project: multiple stakeholder input, timing & phase of engagement etc. In order to validate the proposed framework, 108 projects from all over the world has been applied to test its applicability. The result shows the scorecard improved those projects in term of cost saving, shorter schedule, quality and communication, however, there is no solid evidence to prove this improvement. Moreover, the scorecard will continuously evolve along with the technology (Kam et al., 2013b). Regarding the limitations of this research, the present authors believes:

1. The selection of evaluation criteria has not been validated. The percentage assigned to each area and division lacks explanation. There is no weight has been assigned to each criteria. There is also no standard to judge if the confidence level has been met;
2. The proposed Scorecard is not convenient or reliable for use: the evaluation requires qualified people to interview multiple managers from the organisation, which is subjective. It will also be difficult to decide the true result out of collected results (Du et al., 2014);
3. It will be used in a relatively later stage which is near project completion, while no guidance or priority can be given at the beginning of the project;
4. Kam et al. also realised the evaluator might not be able to complete the evaluation process, as it takes too long.

A cloud-based BIM performance benchmarking application: BIM cloud score (BIMCS) was proposed by Du et al. (2014). This model is based on software as a service (SaaS) to facilitate the data collection and analysis in a dynamic and automatic way. It can be used as an add-in for design platforms (e.g. Autodesk Revit). The model includes six categories: modelling productivity, effectiveness, model quality, accuracy, usefulness and economy.

The first two aspects collect the performance of the product (BIM model) and the rest collect the performance of the process (BIM process). People's daily operation will be monitored and recorded, with a data mining technique, a large amount of information can be collected in relation to BIM performance, BIM application areas and marketing sector. The evaluation criteria was finalised based on literature review and survey. The weighting system for each criteria was first decided through the use of a survey (1-5 scale rating). The weighting system increases in accuracy as the number of users in the aforementioned survey is increased.

According to the present author, the limitations of the research (BIMCS) are:

1. During the criteria developing stage, the removal or addition of criteria was based on the respondents' own judgement; the changes have not been reviewed with others. Moreover, the initial subjective weight obtained from the five-point Likert scale is not accurate;

2. Evaluation criteria is focusing on the modelling perspective, and there is a lack of process, administration and organisational perspective;
3. The performance of the process or product is based on increasing (e.g. building objective in 3D BIM model) or decreasing value (e.g. warnings for error) of the 3D BIM modelling process. However, this might be influenced due to external variables e.g. the complexity of the project, change order from the client etc.
4. The data collection approach has decided the benchmarking object is limited to the technical aspect of n-Dimensional BIM model development process and completed products.

2.5 Conclusion

The review of existing BIM implementation frameworks, standards, guidelines, execution plans, protocols etc. justified that more effective BIM assessment / validation / benchmarking frameworks are needed. The existing BIM assessment frameworks cannot address the issues concluded above; according to the present author, their limitations have been concluded as follows:

1. The source of assessment criteria is mostly based on theory, such as literature review. In order to improve their reliability in practice, questionnaires have been used to obtain empirical evidence (Won et al., 2013). However, participants' suggestion and consensus should be considered for the most comprehensive implementation list (Chen et al., 2014);
2. The weightage of each criteria is based on an estimation value instead of scientific equation (Jung and Joo, 2011, Becerik-Gerber et al., 2012). Their impact towards company's objectives have not been considered to provide a more efficient strategic planning approach;
3. Existing frameworks normally emphasize a single or several aspects of BIM lifecycle adoption (Hartmann et al., 2012, Love et al., 2013, Tsai et al., 2014a). A multi-level organisational approach should be applied to identify the changes to an organisation caused by BIM. Existing methods cannot complement each other due to the assessment criteria and weights are incompatible. Without covering all the relevant implementation issues (Hartmann et al., 2012, Love et al., 2013), it will not be appropriate for new BIM users (Shuo and Jiancheng, 2014);

4. The evaluation framework should be easily updated since its boundaries are evolving in two aspects: software solutions expansion and organisational information systems upgrade (NIBS, 2012, Kam et al., 2013a, Love et al., 2013);
5. Some of the existing methods have not been validated by practical adoption.
6. The relation between each criteria and how they can influence a project's focus scheme are still unclear. By becoming aware this, the decision maker could have the most optimised implementation strategy for improving efficiency (Tsai et al., 2014a);
7. Existing benchmarking tools that been used for cross organisation comparison are not perfect, since most methods' weights were firstly obtained based on a questionnaire, and recalibrated by results obtained from future projects. Considering different strategies could influence the implementation priority of different organisations, the weightage achieved in this way cannot provide a fair comparison environment;
8. Some of the assessment methods and benchmarking tools are not free, which can potentially be ignored by a large amount of applications and reviewer, affecting future improvements.

Chapter 3. Research methodology

In this chapter, the proposed research methodology is introduced first, followed by the overall research design. It includes research paradigm and research techniques used for information collection and analysis; and detailed research procedures, e.g. literature study, case study, questionnaire, Delphi and Analytical Hierarchy Process.

3.1 Research paradigm

Research has been defined by different scholars from different perspectives. Polit and Beck (2004) see research as a 'systematic inquiry that uses disciplined methods to answer questions and solve problems' which aims to 'develop, refine, and expand a body of knowledge'. Oates comments research is a well-designed approach of how the data will be collected and analysed, so as to meet the expected result (Oates, 2006). Lee and Lings (2008) believe research is to develop a knowledge structure in a way 'you believe the world is'. Fellows and Liu (2003) argue research is a process of how the direct and indirect discoveries could be revealed through a carefully designed process and techniques that have been selected. Khosrowshahi and Arayici (2012) summarised research 'reflects the way the authors' beliefs in gathering, analysing, and using data about the phenomenon under investigation'

Khosrowshahi and Arayici (2012) believe there are two research philosophical branches: ontology and epistemology. Ontology focuses on the nature and form of reality, the classification of reality and their relationships (Kuhn, 1970, Lawson, 2004, Oates, 2006). Epistemology focuses on how the theory of the knowledge was perceived by the researcher, the relationship between the investigator and the problem and as well as the capability to judge if the result is accepted (Oates, 2006). Epistemology is also believed as the process of understanding the knowledge of the issue, collecting information and finally to solve the question (Khosrowshahi and Arayici, 2012).

A Paradigm describes the method to collect and explain the knowledge of a certain phenomenon (Saunders et al., 2009). Sauders et al. also believes the classification of a social science paradigm could effectively create new ideas and approaches for practical issues in management and business studies, e.g. positivism, postpositivism and interpretivism (Oates, 2006).

Positivism

There are two versions for the positivism paradigm. The initial concept was created in nineteenth century. It aims to study the fact, using appropriate techniques to observe and measure the phenomenon objectively (Oates, 2006). Moreover, the result based on data analysis could lead to a new research area (Saunders et al., 2009). Positivism is more related to qualitative research since it can be presented by measurable properties (Myers, 1997).

Post positivism

In the twentieth century, social phenomenon was progressed into the study of scientific subject, limitation of the original version of positivism has been detected and a newer version: Post positivism was developed (Corbetta, 2003). In post positivism, people noticed the reality could not be perfectly objective (Oates, 2006). Compared to positivism, post positivism needs to consider potential uncertainty within the research context.

Interpretivism

Interpretivism believes the reality can be either objective or subjective (Oates, 2006). The method focuses on the value, meaning and purpose of the research: how each factor within the context are related to each other and influence the research topic, how this will be changed from case to case. For example, qualitative and subjective methods will be applied if the research is about how the research object could affect its own action (Meesapawong, 2013). There is no absolute reality in interpretivism, the research outcome will be varied based on the interaction between the researcher and the research object. In addition, new knowledge can be created based on this interaction (Khosrowshahi and Arayici, 2012). Therefore, interpretivism is more suitable for qualitative research (Oates, 2006).

Pragmatism - In reality, a single paradigm might not be capable for solving the problem or could not provide the best direction to the issue (Meesapawong, 2013). Another paradigm, pragmatism, was developed for particular research problems. It believes that the character of the research question will decide which research philosophy is appropriate (Wicks and Freeman, 1998). It is also applicable to questions that with a position of positivism or interpretivism since pragmatic paradigm uses all means to collect and analyse the data and solve the problem (Saunders et al., 2009, Meesapawong, 2013).

The framework developed in this research was based on pragmatism with the aim to fully reflect the connection among knowledge, context and practice. The proposed framework collected in-depth knowledge of organisational management, which has been used to identify challenges, validation methods and provide multiple options for the possible direction.

3.2 Research approach

There are two research methods that are adaptable for any type of research paradigm: qualitative and quantitative (Saunders et al., 2009). Existing publications also gives a clear definition and distinction between these two approaches (Oates, 2006).

Quantitative research - was well used in social science research from the late nineteenth century to the mid twentieth century (Creswell, 2008). Quantitative research aims to investigate the nature phenomena according to a carefully designed process of data collection and analysis to ensure the measurement and quantification are precise (Polit and Beck, 2009). Data collected will be in a numeric format, which therefore can be analysed by statistical analysis tools. Methods suitable for this type of research are questionnaires (Oates, 2006).

Qualitative research - was adopted during the second half of twentieth century to elaborate an unquantifiable phenomenon, for example, how humans could subjectively influence a problem (Creswell, 2008). Polit and Beck (2009) argues qualitative research could collect the most comprehensive and in-depth description information based on a number of research methods which may require the researcher's personal involvement e.g. interviews, case studies etc. (Cooper and Schindler, 2003).

The mixed approach - is a research method which contains both qualitative and quantitative method (Wicks and Freeman, 1998, Creswell, 2008, Polit and Beck, 2009), it aims to collect both numeric and subjective data to understand the research problem. It has also been adopted by pragmatism philosophy. A mixed research method is believed to be capable of developing a framework that is able to systematically analyse the component, relevant theory and derivative of that concept (Tashakkori, 1998).

Mixed method has been widely used in many research types relating to management, science and engineering fields, especially in Information System (IS) and BIM related topics (Sebastian and van Berlo, 2010, Khosrowshahi and Arayici, 2012, Goldkuhl, 2012). From Succar's view (Succar, 2009a), such methods could develop a BIM framework which assists researchers to thoroughly to study BIM stakeholders, its deliverables, interactions and its maturity levels.

The implementation of BIM in AEC projects will consist of a huge amount of interaction among stakeholders, project stages, activities under certain constraints e.g. time, budget and sustainability requirement etc. Other than the transformation of technical dimensions, social aspect, such as social-organisational culture will also be involved (WSP, 2011, Khosrowshahi and Arayici, 2012). As such, there is a need to improve BIM practical adoption from a social perspective to provide practical ways of managing BIM in a specific context.

The proposed research adopts pragmatism philosophy, supported by a mix approach (quantitative and qualitative research) where social and other contexts have been comprehensively considered within the research environment.

Considering the problem in the current BIM industry as discussed before, a research methodological framework was developed. Firstly, this research proposed a BIM implementation Framework (BiF) that includes five dimensions and sixty nine criteria. In order to test their applicability in the industry, the proposed BiF will be tested on a real project, following a questionnaire to prove the proposed BiF has considered industry perception, awareness and readiness of BIM. It is also necessary to refine these criteria with consideration of industry users' feedback to ensure no missing element remains behind, a consensus based approach: the Delphi method (a multiple rounds of questionnaires approach) was selected to further refine the preliminary framework in a specific context. As for an assessment framework development, each criteria is required to be allocated with a specific value to represent their weight; should be different from each other. Hence, a group-based decision making method known as the Analytical Hierarchy Process (AHP) method was adopted here as a sensitivity analysis can be carried out to develop new strategic plan (Subramanian and Ramanathan, 2012).

3.3 Research design

3.3.1 Framework Design

In order to provide a consistent and accurate assessment method to make a good decision on the investment in BIM, to improve BIM performance and project outcome, a multiple criteria decision making (MCDM) framework is needed. The MCDM method provides a framework to handle both quantitative and qualitative objectives (Sonmez et al., 2002). This framework can be treated as a platform where all stakeholders could exchange their points of view by following four steps: structure the problem, prioritise the criteria, evaluate and make final decisions (Bozbura et al., 2007). The MCDM has been applied in project management, pre-qualification (Sonmez et al., 2002) and organisational self-assessment (Yang, 2001, Xu and Yang, 2003).

In this research, the author argues BIM implementation in project and organisation management is a process of decision making among a complex integrated environment, which involves both quantitative and qualitative information. MCDM relies upon the constructivist knowledge, which is the interaction between the object (research problem: BIM implementation & assessment) and the subjects (decision maker, DM) (de Moraes et al., 2010). This also requires the researcher to have a minimum possible influence on the DM's choice.

Therefore, the overall design for the research includes two parts: (a) a comprehensive literature study to construct a MCDM framework; and (b) an empirical study - interaction with industry experts including questionnaire data collection and expert experiences (Lyons and Skitmore, 2004), to validate the developed MCDM model.

Figure 3-1 shows the proposed methodological framework, which includes six steps in total, e.g. theoretical study, case study, questionnaire, Delphi expert panel, AHP decision making and validation. They are explained in detail in the following sections.

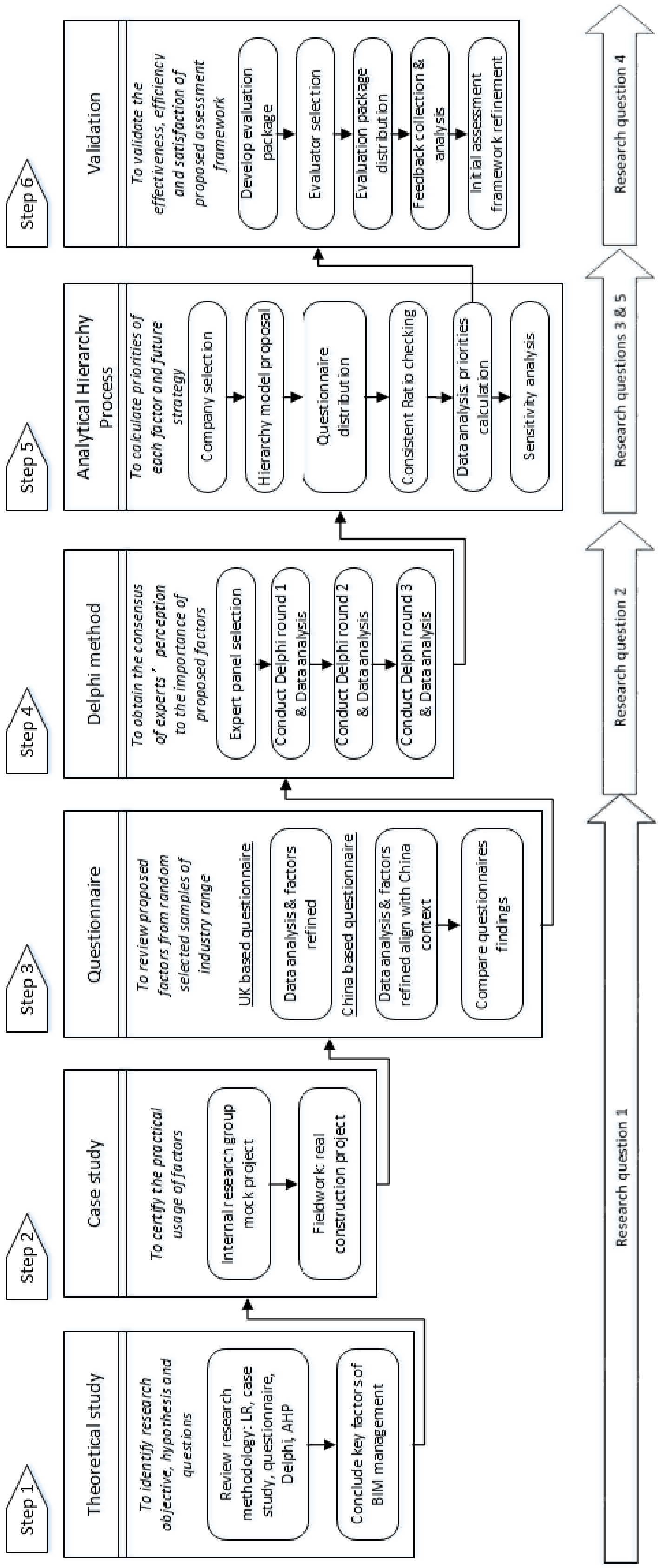

Figure 3-1 A combined Literature review, Questionnaire, Case study, Delphi and AHP methodological framework

This research aims to develop a generic BIM implementation and assessment framework. The literature review conducted covers the most relevant publications worldwide, including both developed and developing countries due to their different maturity levels of BIM implementation. The selection of case studies also aligns with the target, starting from an international construction company, ARUP, with an initial focus on the China ShenZhen branch due to the available resources. The distribution of questionnaire targets at two different countries, UK and China representing developed and developing country respectively.

It is estimated that in 2020, China will carry out 23% of the world's construction projects (Crosthwaite, 2012). With the consideration of low productivity (Adriaanse et al., 2010), a vast number of the resources consumed have been wasted (The Climate Group, 2014). Based on the low maturity of China's AEC industry (HIG, 2015) and the demand for sustainability in the rest of world China is lagging behind (Wong and Kuan, 2014). The huge amount of construction in China could lead to a 'real momentum towards innovation', where BIM is believed as the leading role (CIOB, 2015). However, China's BIM application is still below acceptable levels (Smith, 2014, Miller and Luo, 2015) which is predominantly due to the lack of a systematic management approach on BIM implementation (Gao et al., 2015) and organisation's readiness (Alshawi et al., 2008, Dossick et al., 2010, Khosrowshahi and Arayici, 2012). Therefore BIM is urgently needed in China's AEC industry. Therefore a full scale case study was conducted in China.

3.3.2 Theoretical study (Step - 1)

The review of relevant work could assist with developing a comprehensive, reliable and in a logical multi-level structure implementation framework for BIM (Miettinen and Paavola, 2014, Tsai et al., 2014a). Therefore, a literature review was adopted as step 1 (Figure 3-1) in this research, focusing on the following aspects:

1. Current BIM practices in the AEC industry, e.g. BIM implementation dimensions and factors;
2. BIM implementation frameworks, including standards, guidelines, protocols and project execution plan;

3. BIM assessment and benchmarking frameworks.

Along with the literature review, the 'inductively inferred' process was also adopted, which was defined by Michalski (1987) as 'a process of generating descriptions that imply original facts in the context of background knowledge'. This includes reviewing the background knowledge and other relevant concepts. All information reviewed have been grouped and classified to simplify and explicitly demonstrate the logic structure of the term - 'BIM'.

By the end of this research stage, a preliminary BIM implementation Framework (BiF) has been developed including five dimensions and sixty nine criteria. This preliminary framework will be tested in the next research step in the next section. The proposed BiF was then further revised via a series of steps, i.e. industry questionnaires and Delphi expert panel (detailed in the following sections).

3.3.3 Case study (Step - 2)

There is no model or framework that can perfectly describe reality, but they could be improved and move infinitely closer to it (Dehe and Bamford, 2015). Between various models, there is no wrong model or framework, but one model can be more appropriate than others (Box and Draper, 1987). This can be judged by the accuracy and the usability of the model (Dehe and Bamford, 2015). Research that has a close connection with a real-life context can be validated by empirical evidence through case study methods (Oates, 2006). By adopting a real case scenario, the research assumption can be tested in experiments with sufficient information to be collected (Won et al., 2013).

BIM is a highly practical concept, it should therefore be considered equally important to analyse BIM theoretically (Chen and Li, 2014). The proposed BiF for BIM implementation in the previous step needs to be applicable to industry practice (Kam et al., 2013a). Therefore, the proposed BiF was tested in a practical context, to review those proposed key implementation areas which are valid in a practical use.

Case study was chosen as the second step, using a personal participative based qualitative observation to collect empirical data from practical work routines (Oates, 2006).

In total, two case studies have been undertaken. The first one was a preliminary internal pilot project and the second one was a real project.

Case study 1: internal pilot project

The internal pilot project was conducted within the BIM research group of Cardiff University, where researchers played different roles according to their expertise, such as BIM manager, architect, structural engineer, service engineer and so on. The purpose of this pilot case study was to accumulate experience and solve potential problems during the BIM deployment process, hence to prepare for the industry project that has been selected for BiF validation stage.

Case study 2: real-life case study

The second case study was selected based upon several reasons: (1) a typical building project so it could represent other building projects; (2) the project requires multidisciplinary interaction during the detail design stage as a minimum requirement, and (3) no BIM implemented. All these factors provide a 'test-bed' for the proposed BiF. A deep understanding of the current workflow is required which is essential for the author to develop a tailored BIM plan according to the needs of the local group (Hartmann et al., 2012).

Ethnography and interview methods have been used for this purpose (Oates, 2006). Any outsider involved in an alien circumstance/environment to study its culture and behaviour is termed as an ethnographer. The present author joined the pilot industry organisation and acted as a visitor and learner, invisible to the local employees. By conducting such an approach, it allowed the author to find out first-hand reliable information of current industry BIM practices and its workflows; and how people there work, communicate and collaborate. Moreover, interviews with selected heads of each discipline were also carried out to understand comprehensively about their specific targets, processes, management and workflows.

Based on the observed results, the author have acquired a comprehensive understanding about the current BIM industry practice, therefore a tailored BIM implementation strategy based on the proposed BiF was developed in the second step Two groups of engineers with similar design experiences have been assigned to carry out the same project simultaneously. The author personally led the BIM-based group, while the other group followed the traditional approach. Their outcomes were compared to reveal the differences. Hence the proposed framework was further verified in a practical context to avoid incorrect information being passed into the proposed BiF. More details are included in Chapter 4.

3.3.4 Questionnaire (Step - 3)

Howard and Björk (2008) believe case studies could demonstrate the implementation of BIM in trial projects, however, in order to obtain a wider opinion, the questionnaire method need to be applied to collecting data from a larger range of participants. A Questionnaire contains a set of pre-defined questions, with a pre-determined order distributed to the selected target, e.g. specific regions. The questionnaire method utilizes a self-administered data collection approach, which means the author does not have to be present hence to increase the data collection efficiency (Oates, 2006).

Case studies in step 2 were used vertically to further refine the proposed implementation framework, e.g. using multiple design disciplines from an in-depth level of investigation in a real project; while the questionnaire instrument was applied in step 3 to horizontally expand the validation range, e.g. by collecting the most average trend of information from randomly selected samples that represented the entire AEC industry in a simplified and convenient way (Oates, 2006). It aims to ascertain practitioners' perception, readiness, practice gaps and adoption barriers of BIM and recommendations for future development (Penn State University, 2010, Porwal and Hewage, 2013). Besides, the questionnaire method can also be used to further refine the findings revealed from research step 1, ensuring the factor list is more realistic, and to evaluate whether all key points have been included within the proposed BiF (Chen et al., 2013).

3.3.4.1 Questionnaire design

General questionnaire design requires to consider the following aspects: content and wording, type of question, format of questions and responses, piloting and validity of the questionnaire (Oates, 2006).

In this research, open questions and closed questions have been integrated to facilitate the respondents' opinions. For each question, respondents will face multiple choices to select the answers which are most applicable; along with a blank space for the respondent to enter any other comments.

The questionnaire has been divided into four sections: personal information, organisation information, current practice and BIM adoption barriers. Personal information includes academic qualifications, discipline, and experience in the AEC industry. Organisational information includes history and number of employee. Current practice includes the selection of software, communication approach and data management approach. BIM adoption barriers intends to reveal the most common problems in the current industry BIM adoption. Besides, the length of each question has been designed to be short and appropriate in order to ensure the most valuable data to be collected.

The questionnaire requires *content validity* (Oates, 2006) to ensure data generated through the questionnaire truly meets the need of the research work. Before publication of the survey, the questionnaire had been reviewed through a number of academic staff from the research group, as well as people from industry. This led the questionnaire to a more professional and formal version with improved content validity (Mourshed and Zhao, 2012).

For details refer to Appendix C for UK and Appendix D for China questionnaires.

3.3.4.2 Questionnaire distribution & analysis

The questionnaire was developed based on an online survey tool: SurveyMonkey (https://www.surveymonkey.com/), where all data collected can be analysed automatically, including descriptive information, single choice questions, multiple choice questions and a five point ranking scale (1 presents minimum and 5 presents most important). The analysis of the questionnaire was based on the Relative Importance Method (RII) method (Eadie et al., 2013) :

$$\sum W = W_1 + W_2 + W_n \tag{3-1}$$

$$\text{RII} = \frac{\sum W}{A \times N} \tag{3-2}$$

Where:

W: represents the weight of the option, its value equals to the value of option, e.g. it is 1 when option 1 selected;

A: means the highest weight in the option, which is 5;

N: is the number of respondents in total.

Questionnaire distributed in the UK

The UK has a higher level of BIM industry adoption compared to China (McGrw_Hill Construction, 2014, CIOB, 2015). The rapid BIM adoption and transformation in UK could provide a good example for China to implement BIM fully in the future; Besides to have the questionnaire first done in the UK, it can 'pave the way' to facilitate a questionnaire to be done in other countries with a similar purpose (Khosrowshahi and Arayici, 2012). Compared to other countries who are already at a more mature level. E.g. US (McGrw_Hill Construction, 2014), the UK provides a more incremental progress development process, which is more suitable to China's BIM development. Hence the questionnaire was distributed in UK to reveal the current UK construction industry practice, readiness for BIM, implementation barriers and future development. The questionnaire was conducted between February to October 2012.

Questionnaire distributed in China

In order to reflect an overall status of the current AEC industry and BIM application in China, three provinces have been selected from China's mainland: Shaanxi province (SP), Fujian province (FP) and Guangdong province (GP), as their annual construction outputs are located in various levels (39.97, 54.59 and 77.29 billion GBP respectively (ONS, 2015b)). The construction output has been used as a compilation to measure the gross domestic product (GDP). The difference in GDP could effectively reflect the difference in economies of different provinces (ONS, 2015a). Therefore, data selected from these three provinces could present an average level of BIM of China (Fan et al., 2011, Fan et al., 2015).

Regarding to the policies, cultures, business structures, legislation etc. which are different between UK and China, questions and options within the questionnaire have been modified, a second questionnaire was generated, based on the first questionnaire but with specific modifications to fit China. The second questionnaire was distributed in China from November 2013 – June 2014. The questionnaire results reveal key implementation areas which should be considered within the proposed BiF. For example, those barriers of BIM implementation rated by respondents included in the questionnaire, proved that the proposed model had considered all issues (Memon et al., 2014). In order to improve the comprehensiveness of the data collected, participants were randomly selected from various organisation scale, types and locations.

3.3.5 Delphi (Step - 4)

Delphi consultation was originally developed in the 1950s by the RANO Corporation in one of its projects done with the US defence construction and aimed to 'obtain the most reliable consensus of opinion of a group of experts ... by a series of intensive questionnaires interspersed with controlled opinion feedback' (Linstone and Turoff, 1975).

Delphi method has the following three features (Linstone and Turoff, 1975):

Anonymity

Participants' personal information e.g. gender, age, name and contact information will not be divulged to any other organisation. Answers and relevant comments will not be shared with other individual or organisation.

Iterations

The Delphi method is based upon multiple rounds of a questionnaire approach. By providing participants with a second chance to reconsider their initial answer, as well as using the group's answer as a reference, which can help them to think twice for the most correct answer.

Feedback

Feedback provides a function to help all participants to consider the average or median value of that particular factor's importance in previous rounds, named as a group opinion.

3.3.5.1 Different types of Delphi

The Delphi method has been classified into several types according to the nature of research problem, data collection method and time constraint etc. for example: Classical Delphi, Decision Delphi, Conventional Delphi, Real time Delphi and Policy Delphi (Linstone and Turoff, 1975, Keeney, 2009). In this research, classical Delphi has been selected: as the most fundamental Delphi method aims to collect participants' judgement, analyse it and to be used as a reference in the next round. Normally this process will continue for a minimum of three rounds until consensus among all participants has been achieved. In terms of the communication approach between the researcher and the participants, postal services was be adopted. This type of Delphi meet the demand of this research: to keep the entire process confidential, and participants could provide the most correct and honest answer without hesitation.

3.3.5.2 Delphi expert consultation in this research

The initial adoption of Delphi aims to forecast possible varieties in future (Bender et al., 1969). Bender et al. argues that the present is a summary of the past, therefore, by summarising the present, it could effectively predict the future: Delphi is also believed not only to explore short term decision making but also provide an accurate result for a long term prediction (Ono and Wedemeyer, 1994). Hence it aims 'to determine, predict and explore group attitudes, needs and priorities' (Hasson and Keeney, 2011).

In order to assess the applicability of the proposed BIM implementation Framework (BiF) in a specific context, especially as the initial developed framework may lack latent variables which are difficult to identify or where criteria may overlap with each other, an empirical method is needed to collect opinions from a wide range of practitioners from all disciplines (Du et al., 2014).

The BIM implementation in the AEC industry should adopt multi-dimensional decision making (e.g. project management, organisational management etc.) and stakeholder involvement (e.g. client, designer and contractor etc.). It is important to consider all individual opinions regarding the selection of implementation criteria for decision making purposes. The finalised criteria can therefore be used by a single decision maker instead of a large number of individuals (Sebastian and van Berlo, 2010, AIA, 2013b, Jeong et al., 2013).

Delphi is suitable for multi-dimensional and MCDM problems; it has been adopted for AEC domain to support assessment criteria selection. Hence in this research, the Delphi method were chosen to refine the developed preliminary BIM implementation Framework (BiF). It also addresses the research question: "*What are the most applicable criteria for BIM implementation in the design organisation in a specific context? E.g. China*".

For more explanation of Delphi method please refer to Appendix E.

Work flow of Delphi study in China

The following sections clearly describe the Delphi method steps (Figure 3-2 overleaf).

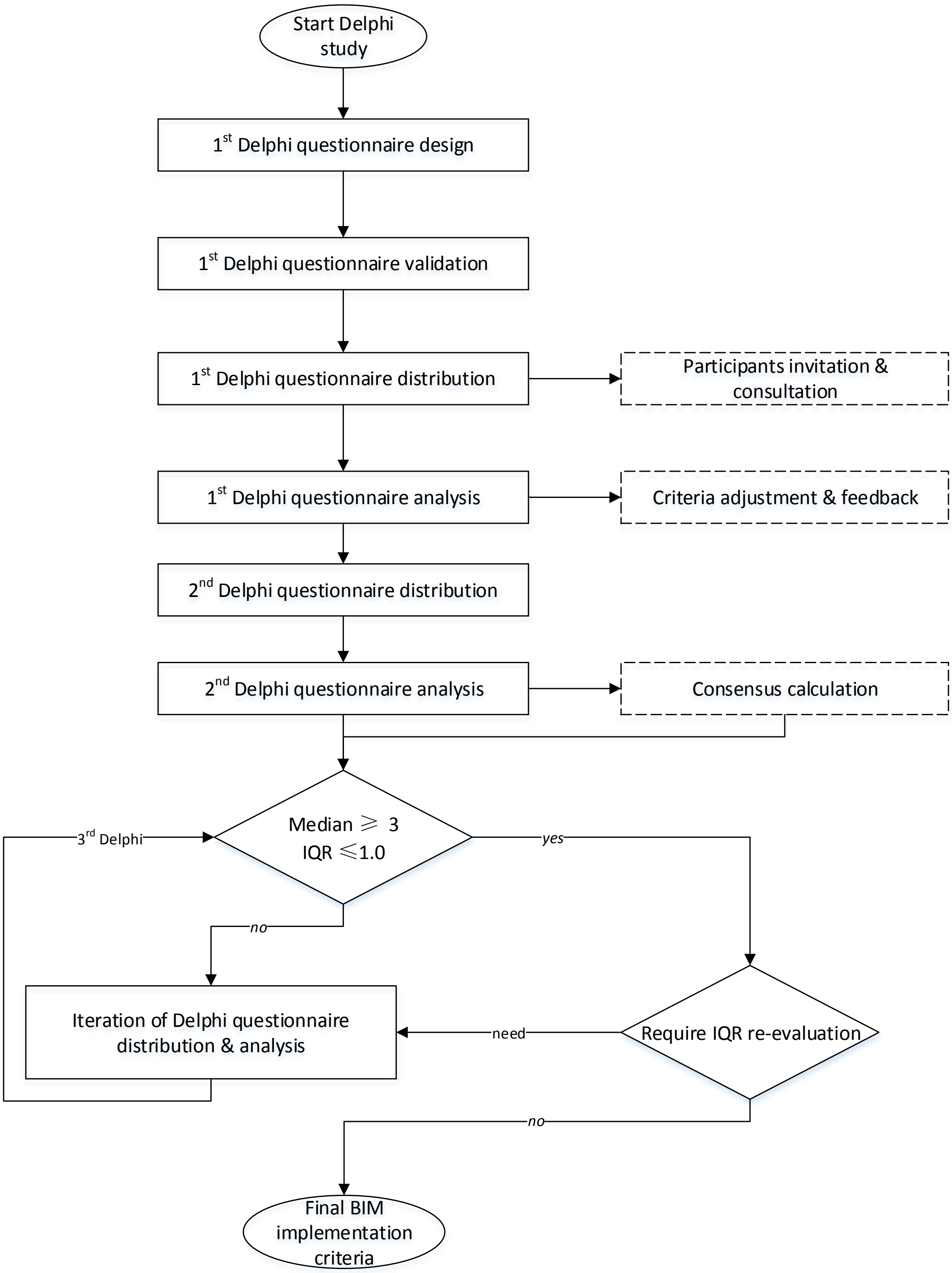

Figure 3-2 Research steps of The Delphi consultation in China

Delphi preparation: questionnaire design & validation

Dimensions and criteria concluded in the BIM implementation Framework (BiF) after research step 3 were used in the Delphi consultation process. The evaluation and data collection process has, through the use of questionnaires been based upon a 5 point Likert type scale to represent participants' judgement (Linstone and Turoff, 1975, Tsai et al., 2014c).

Expert invitation & consultation

The Delphi result should not be affected by location or any discipline, as it requires participants to be selected from different types of organisations, different cities, disciplines and different levels in the hierarchy (e.g. management or design work) (Khosrowshahi and Arayici, 2012).

For the expert panel, the number of respondents should be 'reasonable', and with a focus upon the level of expertise, as too many participants could cause more variation which potentially reduces the accuracy of data (Hasson and Keeney, 2011). Existing research suggests that 10-50 experts is the ideal number (Alyami et al., 2013, Meesapawong et al., 2014).

An official invitation letter was sent to those potential participants before the study for their confirmation (Chien et al., 2014) (Appendix F).

Questionnaire distribution & data analysis

As an iterative process, each round of Delphi has its own objectives which can be realized through data analysis. Results will pass their impact to the next round. The analysis of data were performed by using a developed tool in MS Excel and SPSS. Four relevant performance items have be analysed:

- Feedback: direct communication or comments provided by the participants on which criteria they believe has no importance in the model or which criteria is currently missing from the model;
- Median: order all the answers and the middle one or the average of two values in the middle are the median. Any criterion with a median of less than three will be considered as not important and will be removed from the proposed framework;

- Mean: the average value of all responses from every criterion. Any criterion with an average value of less than three will be considered as not important and will be removed from the proposed framework;
- IQR: known as interquartile range which intends to measure the deviation of the data collected within the range of 25% to 75% (Obrien, 1978, Meesapawong, 2013). A value smaller or equal to 1 shows that a high consensus has been achieved among all respondents;
- Cronbach's α value was calculated to test the reliability of the data collected during each round of the Delphi questionnaire (Chien et al., 2014). The accepted Cronbach's α value should be larger than 0.7 (Tsai et al., 2014a).

To begin the Delphi process, a personal visit by the researcher was carried out: firstly, the researcher gave a presentation of the research purposes and the participants' responsibilities; secondly, the developed BIM implementation framework was explained to the participants in detail, to make sure every criteria was understood. A paper based Delphi questionnaire was distributed at the end of the presentation, and later collected before the end of the meeting. Participants had more than two hours to consider their judgement regarding seventy four questions (five dimensions plus sixty nine criteria). In addition to these results, their feedback was provided as well. The following round of Delphi questionnaire was based on electronic PDF or MS word documents.

The questionnaire for three rounds of Delphi are shown in Appendix G.

Delphi Round 1

Two sections are included in Delphi round 1 questionnaire, the collection of general background information in section 1 and evaluation questions in section 2.

In the first round of the Delphi process, the main purpose was to collect experts' opinions on the comprehensiveness, practicality and applicability of the proposed framework. The median and mean values of each criterion was calculated as well. Any criterion with a value less or equal to 3 was considered to be removed, whereas 4 was considered important (Lu et al., 2008, Tsai et al., 2014a, Meesapawong et al., 2014).

Delphi Round 2

In Delphi round 2, only participants' name and criteria evaluation were collected to facilitate the comparison process. The evaluation questions were slightly different from the round 1 questionnaire, since criteria within the framework have been modified based on the round 1 results. Thus, in round 2 participants were asked to re-evaluate all of the existing criteria's importance level from 1-5, but no feedback was required. In addition, the interquartile range (IQR) was also calculated; a value smaller or equal to 1 shows that a high consensus has been achieved among all respondents. If this is not the case, a third round of Delphi would need to be applied, until the consensus can be achieved (Alyami et al., 2013).

After Delphi round two, all factors must maintain a median and mean value above 3, or they would be removed, and the main objective is to check the level of consensus among the panellists.

Delphi Round 3

The median value achieved in Delphi round two is believed to present an average trend among all panellists, hence in Delphi round 3, the median value of each criterion received in Delphi round 2 will be displayed as a group answer (Hasson and Keeney, 2011). The purpose is to shift an individual's opinion to align with the groups' (Linstone and Turoff, 1975). If a consensus has been met, an IQR of less or equal to 1 will be obtained. If not, another round of Delphi questionnaires is needed.

Follow-up interview & workshops

In order to enhance the rigour and confidence of the Delphi result, firstly a clear definition of the proposed framework needs to be given to the panel at the beginning of Delphi round 1 (Hasson and Keeney, 2011); secondly, a follow-up interview session regarding the participants' impression towards the proposed BIM implementation Framework: BiF is required to ensure the reliability and validity of the Delphi result (Jillson, 1975).

In the current research, an *unstructured interview* was adopted (Oates, 2006). The interview question is simple and straight forward, 'have we achieved the statement mentioned below?' - this BIM implementation Framework has considered all the aspects of BIM implementation. The Delphi result shows all participants agreed that the majority of this framework is correct, all the criteria included are important for effective BIM industry implementation,

3.3.6 Analytical Hierarchy Process (Step - 5)

An analytical hierarchy process approach was initially introduced by Thomas L. Saaty, as a multiple criteria decision making method (SAATY, 1987).

AHP breaks down large and complex problems into small sized factors which are easy to control and manage. By demonstrating these factors into a multi-level hierarchy model, a visual diagram can be created, which will provide the user with a better understanding of the inter-relationship of the entire assessment framework. After the hierarchy model was established, the weight of each criteria will be calculated through the pairwise comparison to demonstrate the relationship amongst all criteria (Wang et al., 2005, Lee et al., 2013). The hierarchy framework was also designed with a few potential options. By conducting the pairwise comparison to identify which option shows the most impact with respect to criteria within the proposed hierarchy framework, the ranking order of those options can be obtained, the highest ranked option represents the attitude of participants of the AHP study (Shapira and Simcha, 2009).

Multi-criteria decision making (MCDM) has been widely used to address engineering, business management, science and technology development issues (Mardani et al., 2015); while AHP as a tool to realize MCDM has been widely applied in AEC industry from both managerial and practical aspects (Subramanian and Ramanathan, 2012, Dehe and Bamford, 2015). AHP can be used for alternative selections for multi-dimensional problems (Jeong et al., 2013, Lee et al., 2013) and assessment purposes (Shapira and Simcha, 2009, Shapira and Lyachin, 2009, Hijazi et al., 2009).

The implementation of BIM within AEC projects involves activities from multiple phases and stakeholders from several disciplines. The activities and associated processes are complex, fragmented and the assessment and evaluation of BIM requires multiple dimensional consideration (Taylor and Levitt, 2007). BIM is at an early development stage which can be defined as “New Frontier Technology”, with the following features: technical uncertainties, market risks, lack of hard data, subjectively and intuitively of evaluation process due to the lack of adequate evaluation criteria and a qualified evaluator (Hsu et al., 2003) and a list of accepted criteria which could facilitate BIM implementation and assessment (Zhu and Xu, 2014). All these have made the evaluation and decision making process for BIM industry implementation very complex.

The development of an assessment method requires two steps (Shapira and Simcha, 2009, Won et al., 2013, Alyami, 2015). (1) Step 1 involves the selection of assessment criteria based on a reliable method, followed by the development of a weighting system. This has been addressed through Delphi method. (2) Step 2 involves a reliable, dependable and applicable weighting system which should be developed to represent the interest of all decision makers from all disciplines and organisation levels (manager and technical engineer). The AHP method could also have the capability to consider the variety of objectives/focus schemes of the organisation. The ranking order of each focus scheme can be obtained to highlight the user's current attitude. In addition, the use of AHP application is rising in developing countries for the evaluation of complex systems (Vaidya and Kumar, 2006). Based on the features of the AHP method, it was adopted in this research step.

For more explanation of AHP method please refer to Appendix H.

3.3.6.1 AHP application in Arup ShenZhen office

The AHP method has been used to apply the developed BIM implementation framework in an international construction company, Arup (ShenZhen office) with an aim to optimize their BIM implementation strategy and to further fulfil their long term organisational goals.

The AHP related work addresses the research questions three: '*How to develop a multi-criteria decision making tool to assist in strategic BIM implementation and assessment for an organisation?*' and research question five: '*How to, by implementing BIM, to achieve the most preferable strategic goals (e.g. sustainability, customer satisfaction and commercial value) for an organisation through altering their current criteria priorities?*'

The AHP application in ShenZhen Arup includes two steps: (1) First, a weighting system was calculated to evaluate their BIM practice against a set of evaluation criteria. That can reflect the weaknesses of their current practices and hence produce a more effective BIM implementation plan. (2) Secondly, sensitivity analysis was carried out to shift the organisation's priorities towards the expected focus schemes. This required a change in the priority of criteria.

3.3.6.2 Work flow of AHP study in China

Figure 3-3 shows the workflow of AHP study in China.

Participant selection

An AHP application is normally case study oriented (Subramanian and Ramanathan, 2012). The Arup ShenZhen office (ASZ) was selected as the study object as they have participated in the previous Delphi methods, which was seen as beneficial to maintain a consistent research environment (Shapira and Simcha, 2009). Arup has more than 35 years of planning, designing, engineering and consulting experience in China (Arup, 2015), it is operated by local people and working with local partners (clients, contractors and government agencies etc.) which makes ASZ very familiar with the culture, policy and business infrastructure of China. The selected company for the AHP study needs to have a certain level of BIM knowledge and experience in managing BIM based projects. BIM concepts should also have been adopted within the entire organisation, even at an initial stage, therefore to be able to propose practical and reasonable BIM project objectives.

With the shrinking of global economics, ASZ currently aims to improve their emphasis on new focused schemes: customer satisfaction and sustainability through comprehensive adoption of BIM, while the transformation has not been successful due to the lack of information or strategy on how to start. Moreover, their decision for a BIM strategy in their current BIM based projects are still based on intuition and without a proper and coherent answer (Jeong et al., 2013). Considering the multiple focus schemes and limited resources, ASZ needs a decision making framework to support a more effective BIM development plan. Therefore, the AHP method was conducted to reveal how each criterion of BIM implementation could influence various focus schemes.

The best participants in the AHP study are those with management and BIM experience (e.g. BIM manager and senior BIM engineer) as they in reality would be managing and adopting BIM. Multiple participants could also avoid any subjective decision making procedures, to make the process (Dehe and Bamford, 2015) and clearly define the evaluation criteria (Chang et al., 2007a).

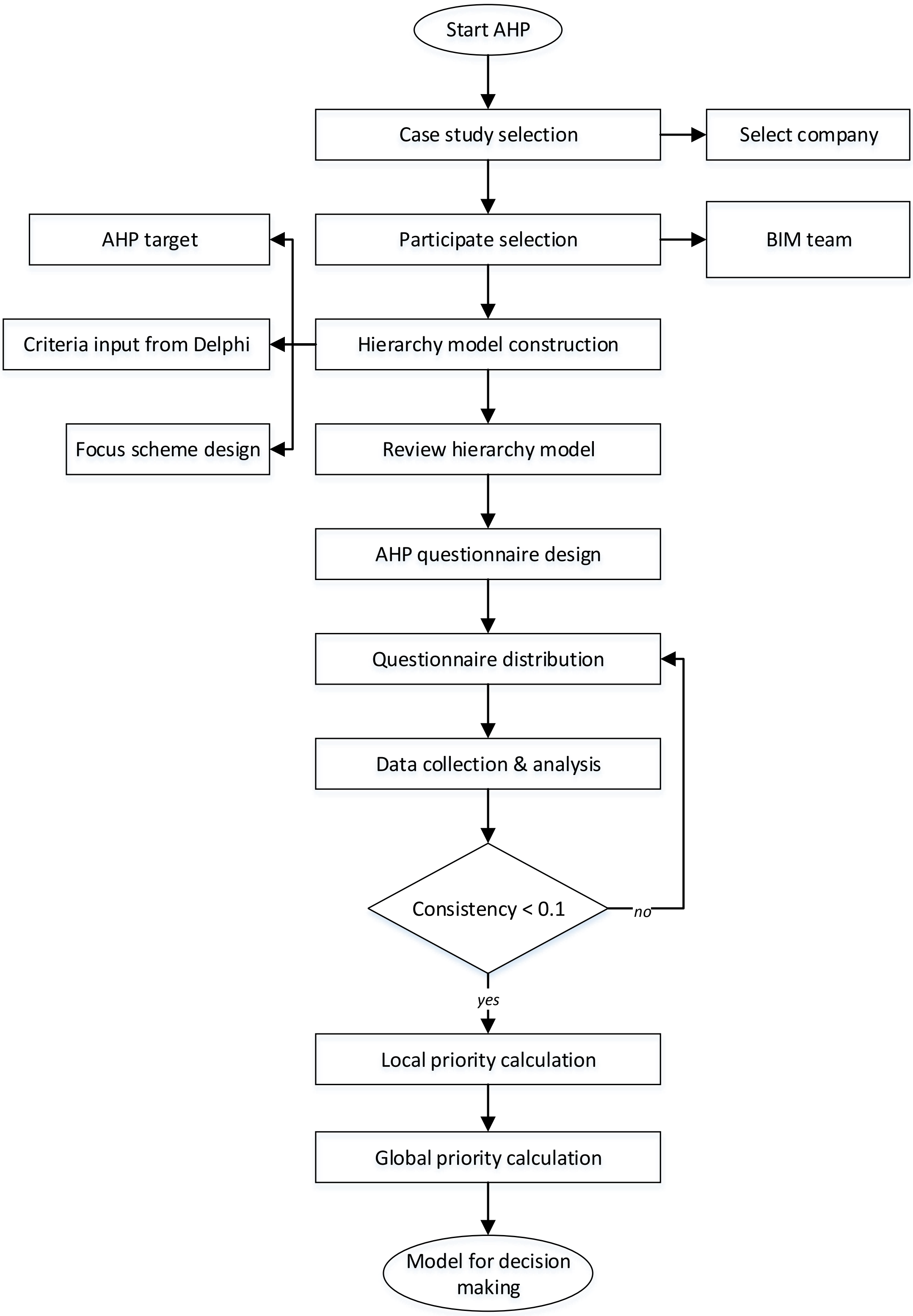

Figure 3-3 Research steps of the AHP consultation in China

Hierarchy model construction & review

To clarify the BIM implementation strategy in ASZ, an analytical hierarchy framework representing how key criteria are related was developed. The author led the initial development of such a model based on ASZ's requirements. The construction of hierarchy model is a process of knowledge requisition, which requires participants to review, make suggestions and approve the model (Shapira and Simcha, 2009). A hierarchy model includes: one target/goal, n Dimensions, n evaluation criteria and three objectives/focus schemes of an organisation or project (Shapira and Simcha, 2009), as represented in Figure 3-4 below.

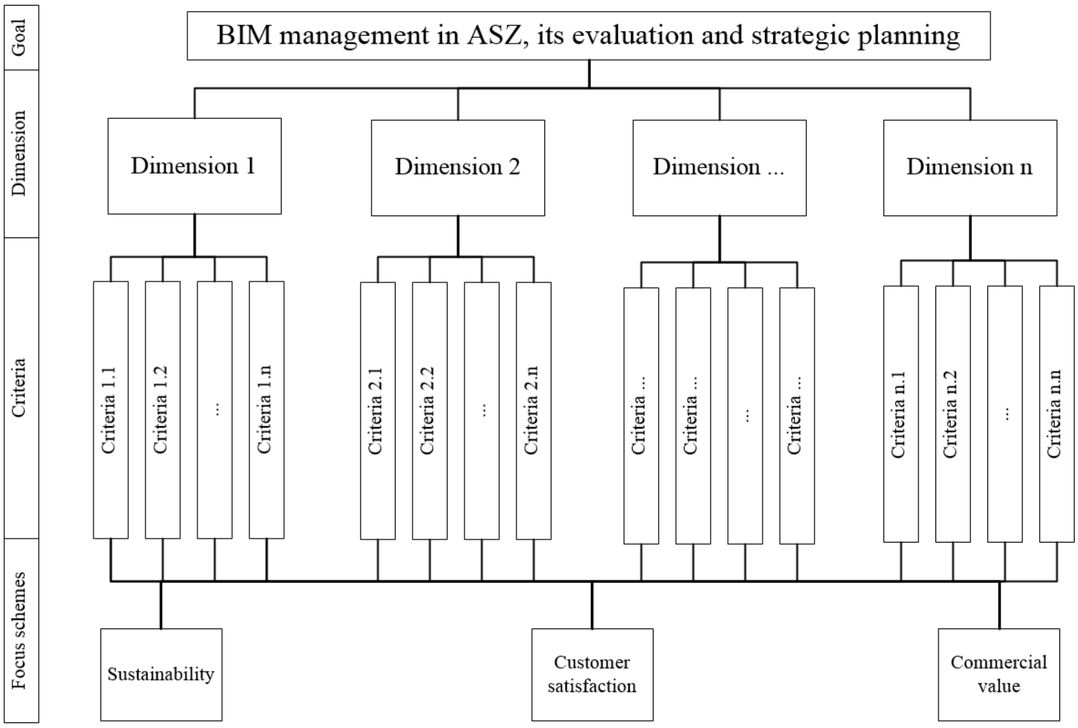

Figure 3-4 A generic Analytical hierarchy framework for ASZ

In the Figure 3-4: the first level shows the target of this AHP study, which defines the goal of the AHP (Gerdsri and Kocaoglu, 2007): 'BIM management in ASZ, its evaluation and strategic planning'. The following levels are the main body of this hierarchy model, which contain those main dimensions, criteria and potential sub-criteria. The last level of the hierarchy model is arranged for the current focus priorities in ASZ.

AHP questionnaire design

After the hierarchy framework has been approved, the pairwise comparison was carried out through the use of a questionnaire (Shapira and Simcha, 2009). Participants rated the importance level based on a ratio scale from -9 to 9 (SAATY, 1987, Lee et al., 2013). The definition of ration 0 to 9 is shown in Table 3-1 below.

Intensity of importance on the ratio scale	Verbal ratio scale	Explanation
1	Equal importance	Criteria of both sides are equally important
3	Moderate importance	Criterion of one side is moderately important than another
5	Strong importance	Experience and judgment strongly favour one criterion over another
7	Very strong importance	A criterion is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between any two adjacent ratio scale	When compromise is needed

Table 3-1 Scale ratio explanation for pairwise comparison (SAATY, 1987)

The questionnaire contains two sessions. The first session was about the comparison among criteria under the same dimension or main criteria, where participants were asked to compare ‘which criterion is more important to BIM implementation in your organisation?’ and ‘how important is it?’ The result delivers a set of weightings for each factor (from 0-1), the summation of each weight must equal to 1. The second session aimed to receive a ranking score for each focus scheme by comparing all focus schemes’ impact towards each dimension and criteria. The summation of all focus scheme weights must equal to 1 as well. The detail calculation formula of the AHP result is present in Appendix I and Appendix J for the completed version of the AHP questionnaire.

3.3.6.3 Sensitivity analysis

The MCDM problem is normally an evolving process (Triantaphyllou, 1997). The requirement and demands of the AEC marketplace varies with time, technology and social needs, the organisation's focus will change and alter accordingly (Zhu et al., 2005). In a traditional approach, decisions and strategies are developed based on the most important factors, however, through some decision making methods (e.g. AHP), a more subtle case can be detected, where less important factors may be considered as significant to the expected target (Subramanian and Ramanathan, 2012).

Sensitivity analysis has been widely used to assist decision making in the AEC industry: a series of well-structured and prioritised criteria is available and their influence effect towards the company's various objectives are provided, understand how each objectives' ranking can be affected due to the shifting of priorities of criteria (Triantaphyllou, 1997, Cole, 2005). Decisions made under such circumstances could provide a more efficient strategy that continuously add value and will pass this down the management chain (Barry et al., 2012, Subramanian and Ramanathan, 2012, Jeong et al., 2013).

In this research, the priority of BIM implementation areas has been changed to meet the organisation's new focus scheme in order to improve the emphasis on sustainability and customer satisfaction. Therefore, sensitivity analysis has been conducted in this research, and thus reveal how each criteria could influence different objectives.

Please refer to Appendix K for more information on sensitivity analysis.

In order to facilitate the AHP analysis process, a commercial software Make It Rational (MIR) (http://makeitrational.com/) was applied to calculate the priority and also conducted a sensitivity analysis.

Based on the weight obtained for each criterion, a BIM evaluation Framework (BeF) has been developed. For the results of AHP study please refer to Chapter 6.

3.4 Validation (Step - 6)

The aim of this validation step was to prove if the proposed BIM evaluation Framework (BeF) could accurately reflect the level of BIM usage in a specific organisation and to test its efficacy (ISO Standard, 2010) and user satisfaction, needs and future development (Gupta, 2013). It also intend to reveal the relationship between the use of BIM and project performance: whether a higher level of BIM adoption could have a positive impact on the project performance or not. Moreover, external variables that could influence assessment results also need to be identified.

The validation work continuously used ASZ as the case study as the weights obtained in AHP step were customised to ASZ. Figure 3-5 below explains the process of validation step in this research.

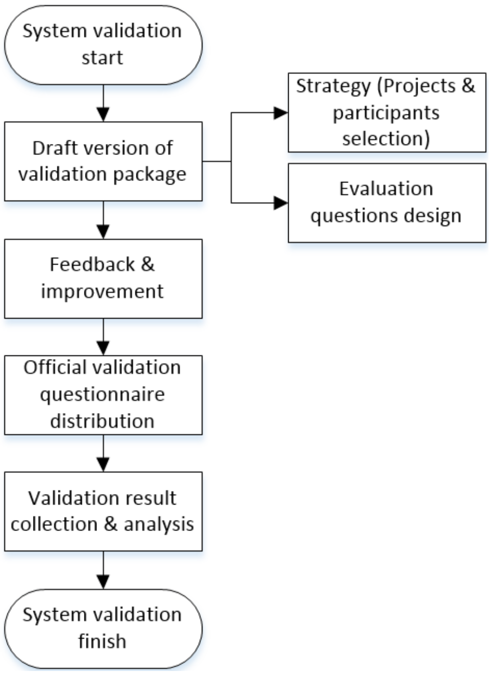

Figure 3-5 System validation process

Evaluation strategy design

The evaluation process was produced by the discussion with BIM manager in ASZ and supervisors in Cardiff University. In order to validate the effectiveness of the proposed BIM implementation and evaluation Framework (BeF), several test projects were chosen to observe whether the application of the developed framework can help to achieve the improved project performance.

Each AEC project is unique (Wegelius-Lehtonen, 2001). This uniqueness is caused by variables such as project location, types of project, contract type and client character etc. (Succar, 2009b), which could all lead to differences. However, there are also similarities led by the unified process of conducting a project, unchanging organisation structure, risk measurement, andante knowledge, and experience (Succar, 2009b). Three rounds of validation questionnaire (Figure 3-6) were produced by working with BIM manager from ASZ. In round 1, vertical comparison was developed to compare different projects' performance by the same team completed during different periods; horizontal comparison was also produced to compare several parallel projects completed by different teams in similar periods. Five projects have been selected from ASZ.

In round 2, any missing / additional information (e.g. project information) from round 1 was identified. Existing assessment tools (e.g. I-CMM, BPM, OBIM & ABMF) were used to assess all selected projects in round 1. Their results were compared to the result obtained by using the developed BeF in round 1. In round 3, user feedback was collected concerning the proposed method. In addition, the result of sensitivity analysis was discussed with ShenZhen ARUP for a new BIM strategic planning to meet their new focus scheme.

Evaluator selection

The user based evaluation is crucial as the result and feedback help to improve the final product to be more effective, efficiency and satisfied product. There is no specific requirement for the number of evaluator (Gupta, 2013). However, there is a difference on the evaluator's expertise and position. The developed BIM implementation and assessment framework is intended to be used by BIM management personnel, hence the evaluator used in this research is ShenZhen ARUP BIM manager since he is the only person who can provide the most objective assessment result.

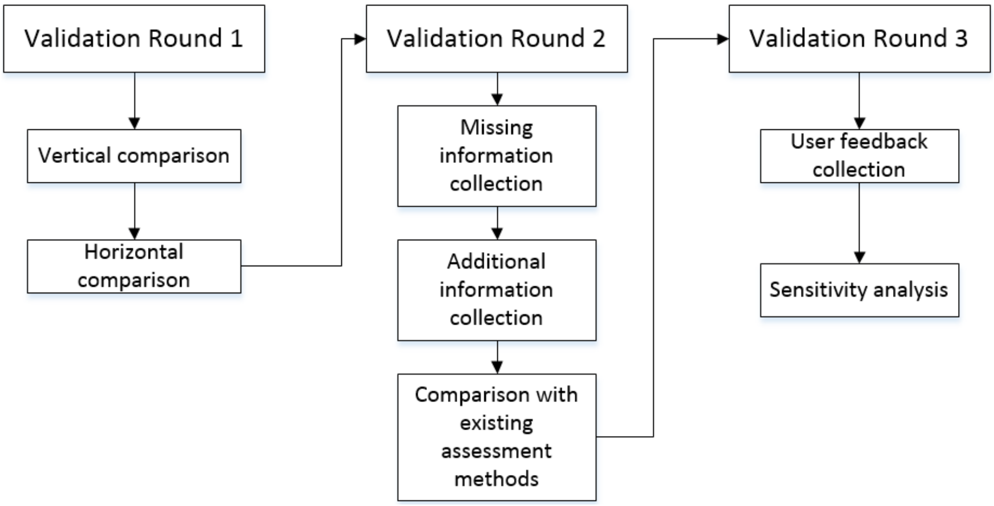

Figure 3-6 System validation design

Validation round 1 questionnaire design

The validation round 1 is based on the questionnaire to evaluate each project based on the following three phases:

1. Phase one. To evaluate BIM usage based on the proposed BeF, the user (e.g. BIM manager) would simply select levels that best meet each project;
2. Phase two: ASZ management team is also interested to know the quality, comprehensiveness and completeness of the nD BIM model that been created and used through the design stage. Since this could reflect user's knowledge, awareness and capability on the development, maintenance, application and management of BIM model, as well as whether those criteria included in the BeF have been truly reflected in the actual result of real project (Sebastian and van Berlo, 2010).
   In this second phase, questions were asked regarding the nD model's naming system, Level of development (LOD) etc. (please refer to Chapter 6 for more detail). User (e.g. BIM manager) would use 1 – 10 Likert scale, where 1 presents the adoption of this particular aspect of nD model is extremely poor, and 10 presents an extremely satisfied level.

The judgement in phase one & two is ideally to be objectively judged. However, the result still can be influenced by many variables.

3. Therefore, the evaluation of project's performance based on various Key Performance Indicators (KPIs) will be included in phase three.

The comparison of those results obtained by all phases could effectively reveal the relationship between BIM levels and project's performance. In order to improve the initial evaluation package to be more reasonable and more comprehensive, feedback was returned to the authors from the BIM manager in ASZ. After appropriate improvement, the final validation package has been send to the evaluator.

3.5 Ethical issues

Ethics are believed relevant to 'obligation, rights, duty, right and wrong, conscience, justice, choice, intention, and responsibility' (Burns and Grove, 2008). Polit and Beck (Polit and Beck, 2004) believe ethics obey professional, legal as well as social obligations to the research participants. Meesapawong (2013) summarised there are three kinds of ethical issues: before the field work, during the data collection process and during the data analysis process.

Considering this research requires a large amount of interaction work with industry, ethical approval was also obtained from Cardiff School of Engineering for all research steps (step 2, 3, 4, 5 and 6) for moral principles. Cardiff University Research Ethics Committee, would review the research methodology and ensure all activities were follow the ethical requirement. In order to comply with the ethics requirement, in this research, the following actions have been taken:

1. An invitation letter was sent to potential participants. The letter would explained the purpose of the research and the participants' obligation. Most importantly, it pointed out they had the right to choose not to participate, and that their personal information and data given would be kept confidential.
2. The questionnaire purpose would be elaborated in the introduction section at the beginning of the questionnaire, this aims to improve participants to clear their role. In addition, the following information would be included:
    a. The participants were informed that they had the right to withdraw from the questionnaire at any point;
    b. Clauses regarding data protection and participant anonymity was printed on the cover page of the questionnaire.
    c. Lastly, instructions were given in order to guide the participants to complete the questionnaire.

3. Permission was requested for releasing result collected from questionnaire for research purpose. Any other information collected during the interview session regarding the organisation's policy, strategy and project information, has been subjected to consultation with the appropriate individuals.

3.6 Summary

This chapter comprehensively explained the generic research methodology and specific methods used in the research conducted by the author. An overall research methodological framework including six steps has been devised to address the concluded research questions. The research follows a pragmatism paradigm with a mix of a qualitative and quantitative method. The six research steps includes one theoretical study and five empirical studies.

Chapter 4. Dimensions & factors for BIM implementation and evaluation

This chapter aims to answer the first research question: '*What are those dimensions and factors for BIM implementation and evaluation?'* This chapter has been divided into three sections, corresponding to the first three research steps. The purpose of the first section is to present the proposed preliminary BIM implementation Framework (BiF) in detail, which was developed based on reviews of existing BIM literature. The second section presents the framework applied in a real project, where BIM's key implementation areas have been tested to prove their usability. The third section presents collected industry perception, level of preparation and current practice in using BIM through questionnaires. This revealed the industry barrier and level of using BIM. The comparison of results between the UK and China, further identified the need for China to improve of its BIM approach.

4.1 Preliminary BIM implementation Framework

The literature review included BIM implementation documents, such as BIM standards, execution plans, protocols, BIM implementation frameworks and assessment tools. By classifying and renaming of terms relevant to BIM implementation, this research firstly developed a preliminary BIM implementation Framework (BiF). In a multi-structured level (Lee and Burnett, 2008), it contains 69 criteria which can be divided into five dimensions, which are ***project management***, ***data management, application management, organisational management and stakeholder involvement***, as shown in the Figure 4-1 overleaf. With regard to the purpose of this research, this BiF could facilitate industry awareness for key criteria of BIM implementation and help BIM management issues (Chien et al., 2014). Considering the wide coverage of the literature review, the developed BiF intended to be generic and to be used with a wide range. The explanation of all dimensions and criteria please refer to Appendix L.

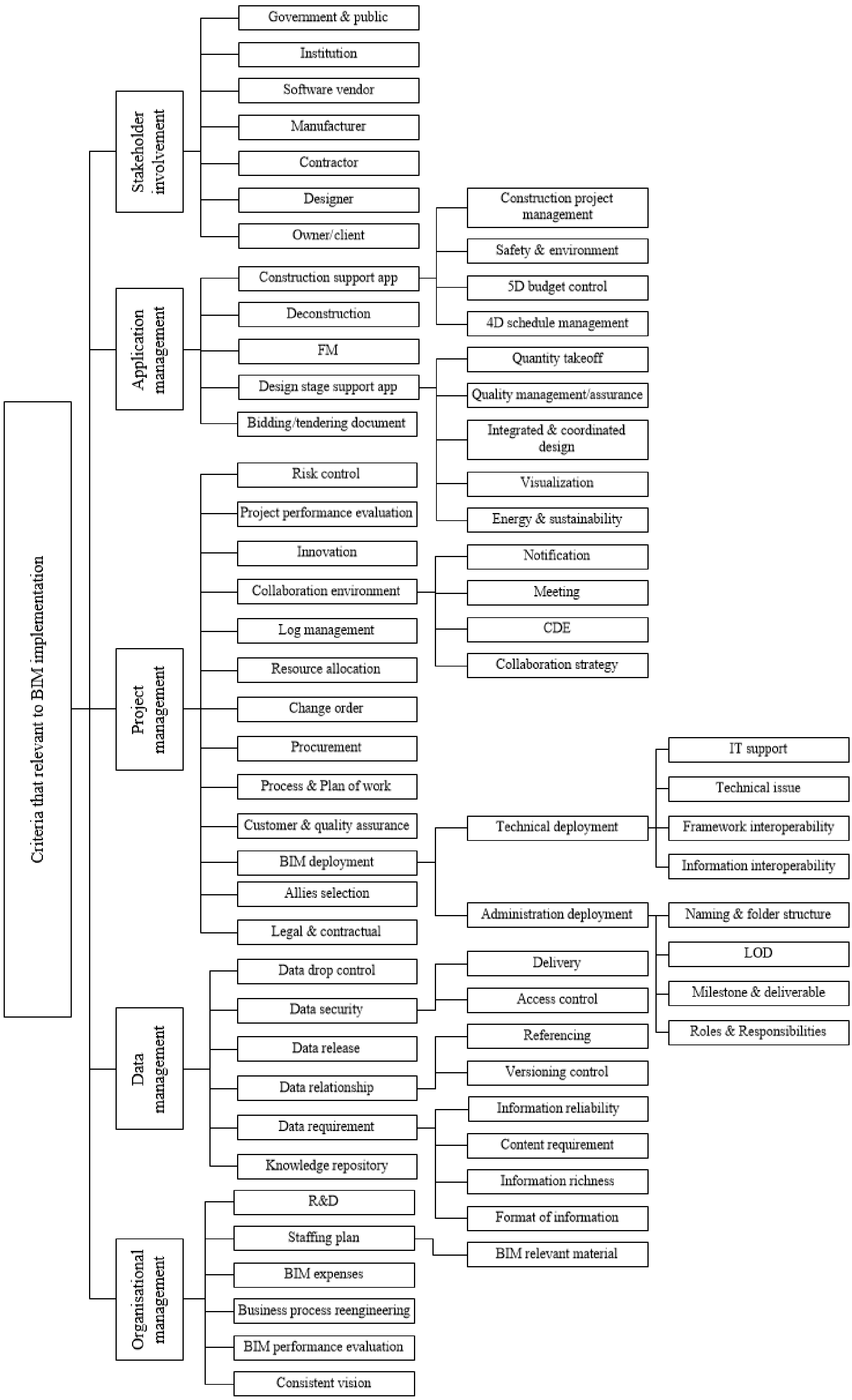

Figure 4-1 The Preliminary BIM implementation framework

These five dimensions as aforementioned has been relatively independent, which allow user to evaluate BIM's capability in each individual dimension e.g. project management, organisational management, data management, application management and stakeholder's involvement. The summation of each dimension's maturity could reflect the overall BIM capability on the entire project. The preliminary developed BIM implementation framework contains five dimensions and 69 factors, which have been further refined via case studies and questionnaire as explained in the following sections.

4.2 Framework enhancement through practical case study

After theoretical study, a preliminary BIM implementation framework has been developed. This section explains using two case studies to have a further trial use of the framework and hence to further refine its practicability. The first case study is a BIM based design project which was carried out within the Cardiff BIM research group (Figure 4-2 below). The main purpose is to have the framework tested in a designed context, where the data management and process of BIM will be studied in a pilot study. In the second case study, the framework and experience gained in the first case study will be deployed and tested a real-life industry BIM project conducted in China. Both case studies have proved the applicability and effectiveness of the proposed framework.

4.2.1 BIM pilot project

Due to the scope of the proposed BiF, the pilot project focused on the design stage of a high rise teaching block designed for Cardiff University. The present author played a role of BIM manager to manage the collaboration between stakeholders, data management, and architectural model design. Other researchers took other roles, e.g. structural engineer and service engineer. Criteria within project, data and application management dimensions have been adopted, such as: naming & folder structure, 3D modelling, multi-disciplinary collaboration, data access control, 4D scheduling modelling and clash detection. In addition, problems during the adoption process have also been summarised and used to further improve the developed BIM implementation framework.

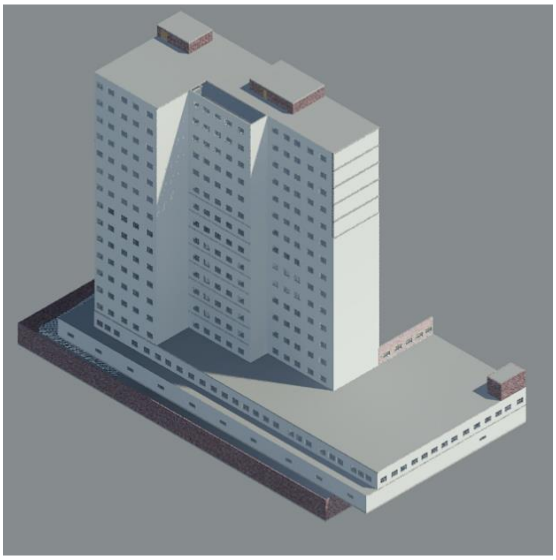

Figure 4-2 BIM pilot project – Revit model

4.2.1.1 Collaboration environment set up

Firstly, the collaboration environment among disciplines has been created. All stakeholders should be able to access the central database constantly, which also requires a well-controlled data management policy to guarantee the safety of data. BIM also requires integrated and collaborative design platform among all stakeholders. The selection of BIM authoring tools therefore should consider issues like compatibility, visualisation, integrated design among disciplines etc.

Revit BIM authoring tools provided by Autodesk have been used for this case study. Two options for data storage and exchange have been tested. Shared Network Drive (SND) was used for internal data exchange. All workstations in the local area network were connected to an Ethernet switch with total transmission speed of up to 1 GB/s. With the consideration of cross organisations activities, Dropbox was selected as an extra central repository where all data was located and shared among all external stakeholders. A proper folder structure and naming convention has been applied as well (AEC (UK) Initiative, 2012).

Revit: Worksets and Link Model

Other than essential modelling capability, Revit also offers Worksets and Link Model functions to facilitate data management and collaboration among users.

When the Revit model file was first created, a Central Model was saved in the Dropbox shared folder. Each designer who would contribute to this model would create a Local

Model on their own workstation. Data belong to the same person controlled by one Worksets to avoid unauthorised access, while others can edit only with the owner's permission. Revit allow designers to upload their changes made in their own Local Model to the Central Model, the Central Model will then notify all other Local Model owner that an update is available for them to synchronise with the latest information.

There might be only one Central Model for each discipline, Revit also allows different model to link each other as references. This brings many advantages, such as automatic model coordination, change notifications and model segregation. The advantages are: first, other disciplines e.g. structure engineer could link architectural model in an earlier stage (e.g. after columns and walls etc. have been placed in position) for them to start structural design earlier with concurrent effort (Fischer, 2006); secondly, if there is any changes from architect side, structure engineer can be notified immediately after the Central Model has been updated.

Navisworks: clash detection, 4D BIM

After all design work has completed, all disciplines' model would be exported into NWC format which is compatible by Navisworks. Navisworks is a coordination software by Autodesk. It overlaps/merges different 3D models to detect any conflicts or clashes. For example, different pipes can accidently cross each other, which is usually hard to identify via traditional approaches.

After all design models have been reviewed for potential clashes, another functionality of Navisworks has been adopted: 4D BIM, the scheduling management by integration of the construction schedule with the design model. The capability of simulation could present the sequence of how the building can be constructed from scratch; this aligned with the construction plan provided from contractor. Moreover, costing information can also be presented for user to monitor the budget information at any point of the construction activities within the virtual environment.

4.2.1.2 Practical adoption issues and solutions

Other than the basic key implementation areas that have been applied in this case study, there are also a number of technical issues which have been identified. In Revit, designer will have to select the expected 'family' to produce the actual building component. However, projects will be different from each other, while there is only limited number of default family for designer to select. The designer would either create a new family to meet the client's need, or use one of the default types to replace their expected one. But both of them could cause problem in future: if the family was not created properly, it could affect quantity take-off (an automated process embedded within Revit) or even cannot be recognised by manufacturer. If a replaced family has been used, more confusion could happen during later construction stage. Moreover, family such as elevator could only be created by highly experienced and skilled designer or even manufacturer.

When the Worksets have been borrowed by another designer with permission of its original owner, the designer have to release the ownership otherwise other users will not be able to use it.

4.2.2 Real-life industry case study

4.2.2.1 Project introduction

In order to best demonstrate the efficiency of the proposed BIM implementation Framework (BiF), an organisation with no BIM background was selected to conduct a real-life project based case study. The organisation was interested in BIM and was willing to fully invest on BIM, including hardware, software and relevant organisational changes.

The selected organisation was Shanghai Architecture Institute China State Construction Engineering Co. Ltd Xi'An Branch (SAIXA), established in 2008. SAIXA has an integrated design department including Architectural team, structural team, construction drawing production team and operation management team which was in charge all the administration work.

This project selected was a two storey steel structural office building in Xi'an, China. The lifespan was designed for 50 years, Seismic Intensity Protection for 7.5 degrees on the Richter scale (UPSeis), and a construction area of 1500m^2. The client was Xi Xian New Developing District, the first national level district of China which requires high level of sustainability in design.

Since that was SAIXA's first BIM based project, they started the BIM process with the training process at the same time. The case study focused on the detail design stage, where the collaboration and data exchange mainly occurred. For the comparison purpose and contingency plan, SAIXA also appointed a second team to apply the traditional approach on the same project, in parallel. This was also used to help them to evaluate the actual benefits of BIM in practice. The case study was carried out from 9th July to 25th August 2011. Figure 4-3 below shows the 3D model of the project.

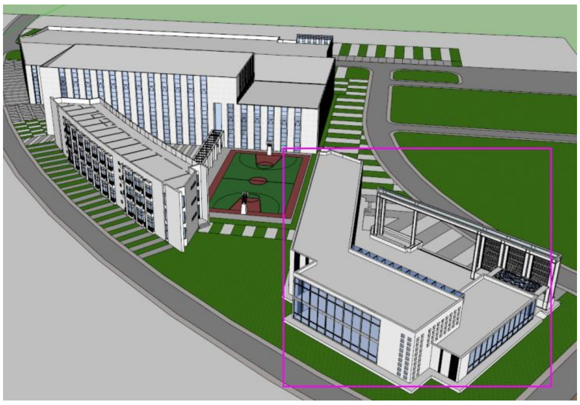

Figure 4-3 Real project based case study in SAIXA, Xi'an, China

4.2.2.2 Case study design

In order to have full support from the organisation, firstly an individual meeting with the owner of SAIXA was arranged. The present researcher explained the research purpose and plan, especially what SAIXA could benefit from this study. The owner agreed that the researcher could have his full support in terms of human resources and financial support.

A group meeting was then conducted, all department leaders were asked to attend. The presentation covered: a brief introduction of what is BIM and how BIM could assist with each discipline's business activities. Individual meetings with each department head were arranged, and that allowed the researcher to observe the current practice at SAIXA using the developed BIM implementation Framework (BiF) as a reference to propose the BIM strategy. The BIM strategic planning was then applied in one of their real projects led by the researcher. Finally, the feedback was collected from the users to further improve the developed BiF.

Each team member were also interviewed individually. The team includes: an executive director, an assistant of the executive director, head of concept design team, head of architecture and construction drawings and mainly responsible for review and approve design work, head of structural design team, a senior plumbing engineer, a senior electrical engineer, a senior HVAC engineer and an administration officer.

4.2.2.3 Observation for existing practices

Existing Design platform

SAIXA is currently using Tangent software (A 2D model development software build on the platform of AutoCAD: http://www.tangent.com.cn/) for design work. With comprehensive libraries that aligning with industry standards, Tangent maximum reduce designers' work load. However, there was no clash detection function available, all clashes can only be detected during construction drawing production or construction stages.

Collaboration environment

All project information were stored in personal workstations. There was no backup policy for the safety of information. The communication and collaboration was very traditional. The exchange of information across disciplines within the organisation, was based on an instant messenger; the exchange of information across organisations with other stakeholders, was also based on instant messenger or email. Since there is no 'published' zone as explained in Common Data Environment (BSI, 2013), all information transferal could only be done by the head of the design department to ensure a correct information to be delivered to the client. An incomplete drawing cannot clearly demonstrate design intention and to support client's next step of work, e.g. contractor selection. This could result in workload accumulation for senior engineer, and delay the project delivery time and decrease the quality. All available working approaches are uncontrolled, as there is no record of the exchange of information. This could result in dispute when a superseded version of drawings have been produced.

Existing work process

Concept design: the concept design team was responsible for developing project proposal for client's approval. The proposal included project functions, construction area, similar business cases analysis and proposed 2D plan views and 3D model for demonstration etc. However, the 3D model is normally based on SketchUp or 3Ds Max, which cannot be continuously used in later design stage. The completed project proposal was then sent to City Planning bureau in 2D format for approval.

Detailed design: after the concept design, architects continued to develop 2D drawing in all views (e.g. plan view, side and elevation view and cross-section view) in a more detailed level. After the completion of the main components of the building, drawings were provided to other disciplines as a starting point for their own work. Different scales of drawings were continuously produced by architect (e.g. 1:100 for overall view; 1:50 for kitchen, staircases; 1:20 for slab detail; 1:10 for roof drainage eaves etc.), which could not be generated automatically. During this process, the architect had to initiate several internal meetings with other disciplines to discuss potential issues and other's discipline requirements. Modifications are expected at all times, along with a large amount of iterative work.

In the meantime, the structural engineer started loads design including point load, line load, area load, external loads etc. Electrical engineer asked for information regarding power and heating requirement from the client and produce drawings based on architect's drawing. Plumbing engineers asked for relevant information of sewerage output and domestic water input.

All teams were fragmented, work process was deprecated: communication was delayed due to relevant stakeholders not being notified immediately or automatically regarding recent changes, thus low efficiency was unavoidable. All disciplines provided their requirements to the architect to update his design, e.g. to rearrange space functions regarding machine room, power supply room and to reserve holes on the wall for electricity wires and piping system etc. Because not all disciplines were involved since the concept design stage, all these led to rework of architectural drawings, recalculation of loadings, all of which would need the client's re-approval. This also caused information losses, inaccuracy and incompleteness. By the end of developed design stage, the completed architecture drawings were then provided to structures team; additionally, cross section view of building components (e.g. column, wall, slab and staircase etc.) were produced to demonstrate their internal structure: reinforcement and steel bar arrangements.

Construction: after the construction drawing have been completed, the drawings would be delivered to the client and the client would appoint a contractor. Since the 2D based MEP drawing is complex, in order to speed up the construction process and avoid confusion in reading drawings, a question and answer session was organised between designer and the contractor before the actual construction started. This also provided assistance for construction strategy development. During the construction stage, regular site visits were arranged, designer has to make sure the actual construction follows plans. Coordination meetings would be proposed if any changes were required. Such changes could be required by the client, due to lack of collaboration between design teams in earlier design stage or limited by the contractor's capability (for example, lack of relevant skill, high cost or high risk). The designer would have to re-design and re-submit for government approval. This could lead to serious construction delay.

4.2.2.4 BIM strategy planning and implementation

After the observation work has been completed, based on the current practices and readiness, the researcher has developed a BIM deployment strategy - the proposed BIM implementation Framework (BiF) was introduced to the team including how BIM should be implemented in an organisation; what are those implementation criteria; how data should be managed under BIM environment; what are the main applications of BIM, and which should be prioritised in the project.

Setting Up the BIM Environment

The working environment is the foundation to allow BIM to be deployed with expected performance. This will mainly include hardware, software and data storage requirements.

Equipment & Facility

The concept of BIM is realised through the use of BIM authorizing tools for modelling, coordination, collaboration and project management etc. Such activities require a powerful workstation especially for modelling and rendering functions. Three workstations with Intel i7 CPU with 3.4GHz speed and 8GB for memory were purchased especially for this case study. Revit 2012 series and Navisworks 2012 have been used for BIM modelling and coordination work.

1. Revit Architecture for concept design, architecture design and energy analysis export tools;
1. Revit Structure for structure design;
2. Revit MEP for HVAC, electricity and plumbing design;

3. Navisworks for 4D simulation and clash detection.

Data management: modelling and storage

In this case study, LAN based shared drive was established to store the Central Model, as all data was mainly exchanged internally during the design stage. All project documents were saved in an appropriate structure and with a specific naming convention according to BIM standards (AEC (UK) Initiative, 2012), with an appropriate storage system (WIP, shared, publish and archive) for convenient document management work. User access was controlled using appropriate ownership rules.

There were two architects working on the architecture model. Worksets function worked well in this case to prevent accidental component deletion. *Send Request* function was used to allow change in element ownership. The original designer would grant permission, and will be informed of changes that have been made by others, for review and approval. This effectively reduced potential disputes caused by model ownership. *Link Model* enables designers from different disciplines to link each other's models as reference to support coordination.

The communication within BIM team is still based on its commonly used methods, such as LAN communication tools, instant messengers and face to face meeting. However, due to model liking, worksets and notification mechanisms provided by Revit, the demand on communication has been largely reduced. Design solution could be consistently and quickly exchanged between members, and that improved their work efficiency. The researcher conducted several training sessions to help designers to use Revit software.

Organisation Management

The existing organisation structure would have to make changes so as to meet BIM requirements. In order to avoid unexpected issues, a new department was established first - its members are the head of each design discipline and the operation department. The researcher took the role of BIM manager to manage BIM based project and reported to the management team about progress and achievements.

BIM based Design Workflow

After the completion of the concept design stage, both teams started at detailed design: the BIM team worked on Revit platform while the other team followed their normal method. In order to maintain a consistent design between two design teams, the same design was used, such as loading system, piping system and electrical system etc. Therefore, the main differences between these two teams were: modelling environment, working process, collaboration method, data management and applications etc.

Set up Project Milestones

The project manager created a schedule (Table 4-1 overleaf) which included: deadlines, main activities and associated model requirements. The entire project progress was monitored by Project Manager and Client. Reasons for delay have been recorded along with the adopted delay solutions.

Data management

The BIM Manager or Project Manager was responsible to set up a standard for data requirements. All BIM models were created in Revit, their formats have to be compatible with other users. Within the model, other than traditional graphical information, non-graphical information was also required, such as price, supplier information, other comments etc. The model was developed comprehensively to meet the requirements for internal and external reviews.

When a new model version was created due to a client change or conflict with other disciplines, the old version was then archived, and a note was attached explaining the reason for change. All changes were agreed and approved by head of department and available to all stakeholders immediately.

The access history and actions were recorded and maintained consistently, therefore Revit can automatically export this information if there is a need to review operation history.

Project Activity	Dead Line	Main Activity	Model Required
Project Mobilization Meeting	26th July 2012	Appoint Project team member and leader, assign tasks and delivery information	Concept Design Model
Construction Site Drawing	27th July 2012	Construction Site Planning	NA (already completed)
Architectural Model	2nd Aug 2012	Produce 3D Model based on	Revit Architectural Model
Material Selection	3rd Aug 2012	Brick and Concrete Supplier Procurement Path	NA
Structural Model	8th Aug 2012	Produce 3D Model	Revit Structural Model
MEP Model	15 Aug 2012	Produce 3D Model (Electrical, Plumbing)	Revit MEP Model (Electrical, Plumbing Design)
Clash Detection	17th Aug 2012	Clash Report and Model Update	Navisworks Management Model & Clash Report
4D Model	20th Aug 2012	Construction Scheduling	4D schedule simulation
Submission for Approval	25th Aug 2012	Submit Design Work to Government for Approval	All BIM model will be Submitted

Table 4-1 Project Milestones of real project in SAIXA

BIM application

Energy & sustainability: from project start, Revit could be used to develop 3D model for Energy Estimation. Environment method such as BREEAM could be used to improve the sustainability of the design. Solar study could also be conducted to help the designer to evaluate the impact of the natural light and shadows on the model in different seasons. All these should have done in an early design stage for the client's reference to come up with a more optimised solution. However, the concept design stage of this project has already completed, and there was no requirement on the energy efficiency or sustainability aspect.

Integrated design: After the initial architectural model was completed, other disciplines such as structural engineer, MEP engineer used 'linking' function in Revit to link with architectural model and copy essential element to demonstrate the design intention of the project, and then to started their own design works.

The developed integrated design environment allowed BIM based collaboration. If anything change in the architectural model, structural and MEP engineer would be automatically be notified by Revit Link Model system; if the structural engineer would like to make any changes on the position of the architectural element, he could borrow the ownership from the architect, to make changes and that will be reviewed and approved by the architect. Architect would continue the design, e.g. to allocate functions to each room, place windows and doors etc. Structural engineer would export completed structural model to Robot Structural Analysis for further calculation. Plumbing engineer will design Domestic Water Supply, Sanitary Waste and Vent and Storm Drainage system. Electrical engineer would design Lighting System, Switch System, Power System and Panel board System. All components will be listed in a new data sheet for quantity take-off purpose.

Clash detection: all design work completed by Revit was exported into NWC format and imported into Navisworks, where clash detection can be conducted among all discipline models. In this project, seven clashes have been identified relevant to the light fitting and the wall.

4D schedule management: after all clashes have been solved, the models were used for further application, a planned construction schedule was designed and applied in Navisworks to demonstrate the construction procedures.

Budget control: the costing information were embedded within the BIM model, and included within the quantity sheet produced automatically by Revit. Relevant information was provided by contractor. Navisworks was used to perform a more detailed costing information: material cost, labour cost, equipment cost, subcontractor cost and total cost. All these information were presented separately in Navisworks schedule simulation and accumulated along with the project progress.

4.2.2.5 Result and feedback

After the case study has been completed, each member of the BIM team submitted a short paragraph on their experience in using BIM and advantages from their own discipline. Main advantages of BIM compared to traditional approach has been shown in Table 4-2.

There are also a number of BIM implementation barriers concluded during the project case study, e.g. (1) the use of BIM concept within design organisation requires significant initial investment. While there are no feasible existing decision making tools to guide the implementation process; (2) There is need for a consensus among all project participants regarding the focus scheme, and therefore to have BIM strategically implemented; (3) The quality/level of using BIM could not be measured. Adoption issues need to be identified. The adoption of BIM should align with the organisation's vision to maximise BIM's advantages.

Practical performance indicators	Description	Group 1: Non-BIM approach	Group 2: BIM based approach	Advantages of BIM
Collaboration	Data communication among various disciplines	-2D based -Fragmented and low efficiency	-3D + non-graphical information -Collaboration with others but limited due to the first time using BIM	Improve the information exchange efficiency within and cross disciplinary
Project schedule management	If the project progress is following the project milestone as planned	Information delivered before the actual deadline but with large effort	Information delivered before the actual deadline with less modelling effort	Reduce work load, modelling time and waiting time, avoid re-work, easily to generate 2D views
Paper consumption	Drawings will be printed for all meetings or discussions	Missing or incorrect information require re-print	Information is correct and complete	All information can be reused, reduce incorrect or incomplete information
RFIs management	Information request for any incorrect or confused drawing	2D based drawing could result in understanding issues in construction stage	3D model assist engineer understand drawing	Demonstrate design intention through both 2D views and 3D model
Clash Detected	Clashes that been detected	Clashes cannot be	Clash has been detected in	Avoid clash in later stage,

	during construction drawing production stage	identified but remain until construction stage	earlier design stage	especially in actual construction stage
Sun Lighting/visualization	Analyse of sunlight	Unknown the effect of sunlight	Proposed design solution can be virtually visualized and sun path simulated	Improve client and designer's visual impression for a better design solution

Table 4-2 Performance comparison between BIM group and traditional group in case study in SAIXA

4.3 Questionnaire for collecting industry perception collection

After the developed BIM implementation framework (BiF) was applied to guide practical BIM adoption in the real-life industry project, questionnaire instrument has been used to collect wider industry perception with an intention to further refine the developed model.

4.3.1 Participants

Questionnaire participants are located in different areas in China and UK, the data collected is believed to be sufficient to present the worldwide construction industry perception. In total, there are 25 participants from more than 21 organisations in Republic of China (ROC), 34 participants from organisations in Guangdong Province, 8 participants from different organisations in Fujian Province, 71 participants from 37 organisations in Shaanxi Province and 54 participants from more than 16 organisations in the UK. The participants' background information shows that all participants have different level of experience and knowledge in BIM from various disciplines, which proves the data collected is able to present the average value.

The Descriptive statistics has been used to describe the background information of survey participants (Table 4-3 overleaf) (Tsai et al., 2014a). However, some participants have skipped certain questions due to privacy, or some participants may have had more than one role, which lead to the summation of certain categories to be more or less than the total respondents.

Variables	Scale/category	UK	ROC	China mainland
Gender	Male	43	17	80
	Female	7	8	19
Age (year)	18-21	1	3	0
	22-25	8	0	10
	26-30	3	8	28
	31-40	14	6	47
	41-50	15	3	13
	>51	6	5	6
Year of experience (year)	<5	12	11	27
	6-10	11	3	43
	11-15	2	3	9
	>16	22	8	25
Job occupation	BIM manager	10	1	0
	Architect / planning	8	4	32
	Structural engineer	1	1	31
	IT Technician	5	1	0
	Civil engineer	5	0	0
	Information manager	4	0	0
	Project manager	4	2	6
	Contractor	1	2	10
	MEP	4	0	8
	Facility manager	1	0	0
	Health & safety consultant	1	0	5
	Others	6	16	15
Highest qualification	College/Pre-university	6	0	1
	Vocational/Technical	11	2	20
	Undergraduate	18	6	47
	Postgraduate taught	12	12	32
	Postgraduate research (PhD)	3	1	1
	Post PhD	0	4	0
Total respondents		50	25	109

Table 4-3 Respondents' personal information in UK, ROC and China Mainland

Their organisations' history and scale are shown in Table 4-4 overleaf.

		UK	ROC	China Mainland
Establishment year	1-10	7	1	18
	11-30	11	13	30
	>30	26	11	48
Number of employee	<10	7	1	3
	11-50	5	1	7
	>50	31	23	83

Table 4-4 Organisations' information in UK, ROC and China Mainland

These organisations are also located in various regions of both countries, as shown in Table 4-5 below:

UK		ROC		China	
London	9	Taipei	6	Guangdong	13
England	7	Kinmen	5	Shaanxi	65
Wales	14	New Taipei	4	Fujian	4
Others	20	Others	10	Others	25

Table 4-5 Participants' location in UK, ROC and China Mainland

4.3.2 Current BIM practice status

In UK, the adoption rate of BIM used in detailed design is the highest (80%) and technical design stage (73.3%). BIM in the construction stage receive a lower value: 63.3%.

ROC has a much higher BIM adoption level than China Mainland (CIOB, 2015), the possible reason is that a smaller market is easier to transform from traditional to BIM based approach. 96% respondents in ROC have heard of BIM, while more than 25.26% respondents in China Mainland haven't heard of BIM.

In term of people's attitude to BIM, in ROC, only 18.18% respondents are not using BIM or showing no interest in BIM, while in China Mainland, 28.21% respondents have no interest in BIM, what's more, 8.97% of respondents currently using BIM consider going back to a traditional approach. 29% BIM users in ROC rated themselves as intermediate user and above, compared to the value of 4.5% in China.

The use of BIM in organisations in ROC and China Mainland is shown in Table 4-6 overleaf, 'Others' skipped this question.

	Non-BIM	Mixed approach	BIM based approach	Others
ROC	8%	68%	8%	16%
China Mainland	4.35%	27.17%	46.74%	21.74%

Table 4-6 Level of BIM using in ROC and China Mainland

4.3.3 Current working environment

Project manager (UK: 54.8%, China Mainland: 56.88% and ROC: 52%) is responsible for the project working environment set up, while new roles and responsibilities will be needed to meet BIM demand (Porwal and Hewage, 2013, Gu and London, 2010). 83.3% UK participants believes there is a need of BIM manager to deal with BIM practical implementation issues, collaboration and data management under BIM circumstance.

4.3.4 Collaboration & communication

Compared to landline, mobile phone and face-to-face collaboration, email can be better managed as it can be used to track and record communications. This is preferred in order to provide evidence when there are legal issues. Therefore it has been ranked higher by UK and ROC. Face-to-face meeting can be more effective, but it is difficult to have this for all cases, therefore mobile phone has been ranked highest in both ROC and China Mainland (Table 4-7).

	UK		ROC		China Mainland	
Landline	3.88	3	3.84	4	3.09	5
Mobile phone, SMS	3.76	4	4.38	1	4.19	1
Email	4.36	1	4.24	2	3.79	3
Teleconference	3.13	5	2.95	6	2.4	6
Online voice/video meeting software e.g. Skype	3	6	3.57	5	3.77	4
Face-to-face meeting	4.23	2	4.19	3	4.02	2
1-5: 1 = no important; 5 = very important						

Table 4-7 Communication method in UK, ROC and China Mainland

In term of data storage, both UK and ROC have their data kept in the organisation's internal server. China Mainland prefers to keep most data on personal workstations, which could cause access, safety back-up issues. In ROC, Data exchange is based on organisation's internal intranet, UK is based on email while China Mainland still mainly relies on paper-based exchanges (Table 4-8).

	UK				ROC				China Mainland			
	Storage		Exchange		Storage		Exchange		Storage		Exchange	
Paper	3.29	2	3.32	3	2.14	7	3.65	4	3.23	2	3.94	1
Optical media (e.g. CDs, DVDs, etc.)	2.94	5	2.73	6	3.45	4	3.5	5	2.74	5	2.98	6
Flash storage (e.g. USB, Memory Card, etc.)	3.06	3	2.78	5	3.8	3	3.79	3	2.93	3	3.73	2
Email	/	/	4.24	1	/	/	3.75	2	/	/	3.62	3
Networked drive in the company intranet (e.g. NAS)	4.15	1	3.76	2	4.26	1	3.91	1	1.97	6	3.05	5
Portable external hard drive	2.38	7	2.18	7	3.33	5	3.43	6	2.76	4	3.3	4
Cloud storage solution (e.g. Dropbox, Amazon S3, etc.)	2.81	6	2.97	4	2.84	6	3.26	7	1.94	7	2.34	7
On my pc/laptop drive	2.94	4	/	/	4.16	2	/	/	4.08	1	/	/
1-5: 1 = never; 5 = always												

Table 4-8 Project data storage and exchange method in UK, ROC and China Mainland

The format of document used for data exchange is mostly based on PDF and AutoCAD DWG. However, UK has a relatively higher frequency to exchange Revit file (4.06) among stakeholders (Table 4-9 overleaf).

	UK		ROC		China Mainland	
PDF	4.55	1	4.24	1	3.67	2
AutoCAD (.dwg)	3.06	4	3.79	2	3.92	1
Revit (.rvt)	4.06	2	3.0	4	2.16	5
Bentley (.dgn)	2.0	6	1.88	6	1.89	6
IFC	2.63	5	2.35	5	2.23	4
Image formats	3.67	3	3.74	3	3.48	3
1-5: 1 = never; 5 = always						

Table 4-9 Project data storage and exchange method in UK, ROC and China Mainland Data exchange format in UK, ROC and China Mainland

4.3.5 Software

The use of software could reflect the level of BIM adoption in one organisation. AutoCAD based traditional approach still has a dominant role especially in China Mainland. Revit has been used in a similar level in UK and ROC, but much lower in China Mainland. Other BIM authoring tools like Bentley and ArchiCAD have achieved a higher usage rate in UK (Table 4-10).

	UK		ROC		China Mainland	
Autodesk AutoCAD	31.25%	1	28.95%	1	71.91%	1
Autodesk Revit	26.39%	2	26.32%	2	4.49%	3
Bentley	13.89%	3	5.26%	4	4.12%	4
Graphisoft ArchiCAD	9.03%	5	1.32%	5	0.37%	5
Google SketchUp	12.5%	4	13.16%	3	8.61%	2
Others	6.94%	/	25%	/	14.6%	/
Total	100%	/	100%	/	100%	/

Table 4-10 Software usage for design in UK, ROC and China Mainland

For model coordination, Navisworks has been used more than Solibri. Navisworks and Solibri have occupied more than 60% of ROC's industry practice together, which is much higher than that of UK and China Mainland (Table 4-11).

	UK		ROC		China Mainland	
Navisworks	24.39%	1	33.33%	1	22.14%	1
Solibri	9.76%	2	29.41%	2	14.29%	2
Others	65.85%	/	37.25%	/	63.57%	/
total	100%	/	100%	/	100%	/

Table 4-11 Software used for model coordinate in UK, ROC and China Mainland

4.3.6 Barrier and solutions

The top ranked BIM adoption barrier are shown in Table 4-12:

Data management issue: data inconsistency	82.9%
Team member's resistance to change	80.56%
Lack of BIM knowledge	75%
Lack of compatibility between traditional and BIM tools	72.2%
Software cost issue	70.6%
Lack of relevant contract clause especially for BIM	67.6%
Lack of training	66.7%

Table 4-12 BIM adoption barriers in UK

In China, participants' responses are ranked in Table 4-13 below:

	Importance level & ranking			
	ROC		China Mainland	
Lack of training	3.4	4	3.44	1
Software cost	3.58	3	2.67	6
Lack of BIM knowledge	3.85	1	3.23	4
Client not require BIM	3.16	6	3.16	5
Local authority not require BIM	3.35	5	3.26	3
Client not willing to pay for BIM cost	3.76	2	3.31	2
1-5: 1 = no important; 5 = very important				

Table 4-13 BIM adoption barriers in ROC and China

UK shows that its main barrier lies on data inconsistency where BIM has been used. Barrier relevant to training and cost has received less attention. While in China, its BIM adoption is still in an initial stage, the highest selected barriers are the cost issues and people's knowledge and awareness of BIM.

Participants from ROC concern there is insufficient knowledge in BIM, while China Mainland noticed there is no enough training on how BIM should be adopted and managed in actual project. ROC organisation normally has a tight budget for software purchases, while China Mainland does not have relevant policy to push BIM from the local authority's side.

For the future development of BIM in UK, respondents rated it should have a focus on the collaboration, communication, clarify roles and responsibilities under BIM environment and shared data base among all stakeholders, as shown in Table 4-14.

	Importance level	Rank
A notification system to inform team members of updated data	4.29	2
Central repository for data storage online	4.11	4
Provide real-time mechanism for share/exchange information	4.18	3
Improve the communication among disciplines	4.38	1
Define clear roles, responsibilities for stakeholders across discipline through lifecycle.	4.38	1
Standardised overall life cycle data management policy	4.04	5
1-5: 1 = no important; 5 = very important		

Table 4-14 Future improvement of BIM in the UK

Regarding the adoption barriers of BIM in China, participants from ROC believe sufficient training (3.55) and localised 3D library component (3.5) are more urgently needed than people's awareness (3.26) for BIM implementation in practical project. While in China Mainland, it is urgently need to improve people's awareness in BIM (4.28), followed by BIM training (3.8) and appropriate software (3.71) provided. As shown in Table 4-15 below:

	Importance level & ranking			
	ROC		China Mainland	
Internal collaborative platform	3.33	4	3.25	8
BIM software development	2.74	8	3.31	7
Software consider local cultural	3.21	7	3.71	3
BIM training	3.55	1	3.8	2
People's awareness in BIM	3.26	5	4.28	1
Data interoperability	3.1	6	3.64	4
External collaborative platform	3.38	3	3.6	5
3D library component	3.5	2	3.32	6
1-5: 1 = no important; 5 = very important				

Table 4-15 Future improvement of BIM in ROC and China Mainland

The questionnaire result also revealed that the best way for BIM training in both ROC and China Mainland is to have systematic training conducted by an external professional organisation (ROC: 3.7; China Mainland: 3.69), such as BIM consultant or research institutions. There is also a considerable argument to outsource BIM modelling work (ROC: 2.6; China Mainland: 2.42) (Table 4-16).

	Importance level & ranking			
	ROC		China Mainland	
Outsource BIM related work	2.6	4	2.42	4
Self-learning	3	3	2.79	3
Internal training	3.14	2	3.62	2
External training	3.7	1	3.69	1
1-5: 1 = no important; 5 = very important				

Table 4-16 Preference in training approach in ROC and China Mainland

In order to achieve the maximum efficiency, the training should focus on the most needed aspects: participants from ROC need training for BIM modelling skills and process (3.75) most, followed by the integration of BIM with existing approach (3.67); while for China Mainland, the training should first focus on how to integrate BIM concept with traditional approach (3.75), followed by the basic functions of BIM (3.68) and needs for appropriate training (3.63) (Table 4-17).

	ROC		China Mainland	
Basic functions of BIM	3.35	5	3.68	2
Collaboration with others	3.52	4	3.29	5
BIM modelling skills and process	3.75	1	3.63	3
BIM model exchange	3.32	6	2.77	6
Integration of BIM and existing approach	3.67	2	3.75	1
Parametric design	3.53	3	3.57	4
1-5: 1 = no important; 5 = very important				

Table 4-17 Focus of training in ROC and China Mainland

Risk control at both project and organisational level is necessary to ensure the project's profit. Majority of the participants believe this is positive towards a more profitable outcome (ROC: 79.17%; China Mainland: 70.21%). More than half of the participants already have such measurement in their organisation (ROC: 50%; China Mainland: 59.14%), and more than 8% of the participants from both region have the plan to adopt such measurement in their organisation.

Table 4-18 shows the government roles in BIM implementation. UK government has published several BIM strategic plans, such as: policy of adoption BIM and funding available for BIM relevant research (Office, 2011). In ROC, people already aware the importance of BIM, which lead to the need of relevant policy (4.24) and funding (4.24) to push BIM to the next level. However, in China Mainland, government agencies will need to improve people's awareness (3.85) on BIM, followed by publishing relevant guidelines and standards (3.55) for practical adoption.

	Importance level & ranking			
	ROC		China Mainland	
Policy of BIM	4.24	1	3.37	4
Publish guidance and standard of BIM	4.1	3	3.55	2
Enhance supervision and monitor	4.05	4	3.31	5
Provide funding	4.24	1	3.19	6
Provide and enhance associated trainings	4.14	2	3.45	3
Improve people's awareness on BIM	4.14	2	3.85	1
1-5: 1 = no important; 5 = very important				

Table 4-18 Government's role in ROC and China Mainland

4.3.7 Summary

In this research step, a questionnaire method has been used to collect industry perception regarding BIM industry adoption for UK and China (includes China Mainland and Taiwan - ROC). The use of questionnaire intends to collect data from randomly selected samples to analyse the current adoption level of BIM, people's awareness and readiness, barriers and suggestions for future development of BIM.

A clear picture on how BIM applied in industry has been concluded; the comparisons have been carried out between the result collected from UK, ROC and China Mainland. In order to address the differences between UK and China, questions and options used for the questionnaire have been modified. The result shows China Mainland is behind UK and ROC in every aspects in terms of BIM adoption. The findings regarding the weakness of current practice, adoption barrier and future development of BIM have been included in the further development of the proposed BiF.

By going through the aforementioned three research steps – literature review, trial cases studies and questionnaire survey, the developed BIM implementation Framework is believed as applicable and generic for a practical context. It will be further used to develop an evaluation tool for organisation to make strategic decision making towards better BIM adoption. Delphi panel and AHP methods are the last two steps to achieve that target.

Chapter 5. Delphi based BIM Implementation Framework Refinement

5.1 Overview

Research step four aims to finalise those important dimensions, factors and criteria for comprehensive BIM implementation by using focused Delphi expert panel. In order to achieve a consensus and to have those criteria agreed by all user without compromise, the Delphi method has been adopted in this research step, with its all participants from China. By the end of this step, a fully functional BIM implementation framework has been completed and is ready for wider industry trial.

5.2 Delphi round one

The first round of Delphi questionnaire contains two parts: 1) participant background information and 2) criteria importance evaluation. In the first part, participant age, discipline, experience, qualifications etc. was collected to prove they are qualified to judge the importance of each criteria. The second part has assessed the importance level of each criteria based on a five-point Likert scale, where 1 represents not important and 5 most important.

The panel selection is the decisive factor for success (Jillson, 1975, Hasson and Keeney, 2011). Therefore a strict policy on the selection of organisations and participants was proposed and followed in this research in order to collect the most comprehensive, reliable and convincing data (Chien et al., 2014, Meesapawong et al., 2014).

Six prestigious design and BIM expert consultant organisations were invited, (Table 5-1) according to the following criteria:

1. Each organisation should have a minimum 3 years' experience of adopting BIM; in fact, the selected organisations are the first users of BIM and have contributed to the development of China BIM standards;
2. BIM based project experience in all types of project e.g. housing, health care, corporate, sport, education, etc.

3. Their roles and responsibilities mainly cover the design stage but still maintain a close interaction with other stages (e.g. construction & operation stage).
4. Geographical difference to reduce perception and phenomenon affected by localisation; all organisations as well as their branches are located in different regions of China, while their businesses are all over China and mostly globally, therefore to show an average phenomenon of China;
5. Multiple types of organisations were selected to collect perception from multiple aspects; such as global design and consultant organisation, local design and consultant, government owned design and research institution etc.
6. The organisation should have diverse nature of disciplines to collect various experience and perception from individual

At the initial analysis stage of framework developing, it is believed that considering all variables is necessary in order to obtain adequate results (Giel et al., 2012). Table 5-1 presents the organisations' information.

Company name	Type of company	Business scope	Company scale	Experience in BIM (years by 2014)
ShenZhen A+E Design (AE)	Local AECO design company	Global	Large	6
ShenZhen Institution of Building Research (iBR)	Building research, consultant & design company	Global	Large	6
isBIM Limited (isBIM)	BIM expert consultant	Global	Large	6
Arup ShenZhen office (ASZ)	Independent international design company	Global	Large	6
Xi'An Architectural Design-Research Institute (ADR)	Building research + Design company	All over China	Small	5
Shanghai Architecture Institute (SAI)	Local AEC design company	All over China	Large	3

Table 5-1 Qualified organisations for Delphi method

Shenzhen A+E: One of the largest construction design companies in ShenZhen, China. Its business includes all areas of design work with projects inside and outside China. Inspired by European and North American's BIM projects, AE has started to implement BIM in their project since 2009, right after the first wave of BIM (Won et al., 2013). An independent BIM group of 12 people from design team, management team and construction team was created; they adopted both software and hardware advances to bring in extra support.

ShenZhen iBR: Shenzhen Institute of Building Research Co. Ltd was founded in 1992. Initially it was just a research institute and later became a national high technology enterprise in 2013. iBR focuses on city and architecture research, planning, and consultation, and evaluation services in area of: engineering, environment, energy, sustainability. iBR also has participated in the development of the BIM standard for China and established their own BIM department strategy.

isBIM limited: Established in 2009, as the only authorised Autodesk training centre in China, it provides leading expert BIM consultancy including training to design companies, clients, contractors and asset operators. They are the co-author of "Research of Chinese BIM Standard Framework" with Tsinghua University in 2011. Together they also published "Guidelines of BIM Implementation Standard for Design Enterprise" in 2013. isBIM also has branches in other cities e.g. Beijing, Chongqing and Hong Kong etc.

Arup ShenZhen office (ASZ): Originally founded in 1946 with expertise in structure design, and now it provides design and all kinds of consultant services. ShenZhen branch has established for more than 35 years and participated most stunning projects in China. Arup encourages collaboration with institution for future technology and business exploration. With the emerging of BIM, Arup realized BIM is its new business opportunity and established Advanced Technology Group to make further development.

ADR: One of the largest design and research company in north China, they have a great enthusiasm in using BIM. They are one of the first CAD users in China, and also the first BIM users in China since 2010.

SAI: One of the largest local design companies. They are one of first CAD users in China, and now keen to use BIM throughout their organisation.

52 BIM users (Table 5-2) have been invited from the BIM department of the selected organisations (and their branches in other cities of China) with 8-12 participants per organisation. The selected participants play different roles in their organisations:

1. Director/CEO and technical director: has a unique view, control of BIM development in the company and a long term vision of BIM in China's industry;
2. BIM manager, BIM expert and BIM senior engineer of the design team who may have consistent knowledge, expertise and experience in BIM in practice;
3. BIM engineer or experienced consultant who could have a better knowledge and experience in BIM implementations.

The summation of each category might different from the number of participant in Delphi round one, as some of the respondents have more than one roles or they skipped few questions to remain anonymity. The selection of multi organisations and various roles and disciplines could avoid group bias and consider the diverse nature of jobs that bring various perceptions (Hasson and Keeney, 2011).

Figure 5-1 shows the date of Delphi round one distribution and collection:

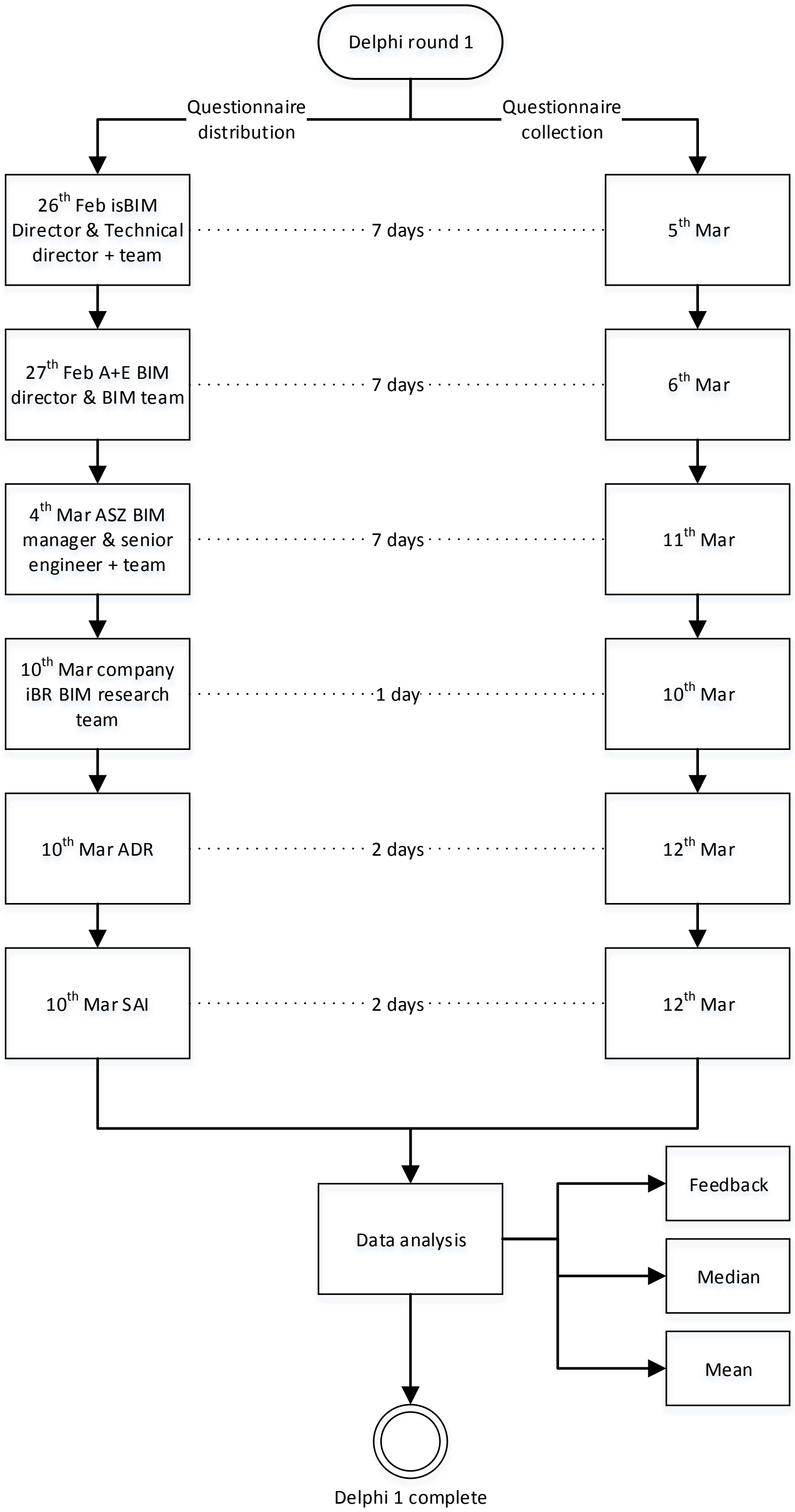

Figure 5-1 The workflow of Delphi round one questionnaire distribution and collection.

Descriptive statistics has been adopted here to represent the background information of all participants (Table 5-2 overleaf) (Tsai et al., 2014a).

	Categories	Number of person
Gender	Male	35
	Female	17
Education info	Ph.D.	2
	M.Sc.	12
	Bachelor	37
Professions	Structure engineer	17
	Architect	16
	MEP	12
	Cost estimator, planner, BIM sales, real estate, researchers	9
BIM activity	BIM project manager	6
	BIM model manager	8
	BIM researcher	13
	BIM modeller	23
	BIM user	12
	BIM maintenance	2
	BIM model coordination	10
BIM experience	>7 years	6
	5-6 years	10
	3-4 years	16
	1-2 years	18

Table 5-2 Respondents' background information in Delphi round one

The data analysis conducted includes feedback analysis, median and mean value calculations:

1. Feedback: direct communication or comments left by the participant on which factors are of little or no importance, or which factors should be added to the model;
2. Median: order all the answers and the middle one or the average of two values in the middle are the median. Any factor with a median of less than three will be considered for removal from the factor list;
3. Mean: the average value of all responses from every factor. The calculation of the mean value is not very common in the Delphi type of research. However, it was noticed that, any factor that has a higher median value may have a small mean value, which also should be considered and removed from the model.
4. Cronbach's α value will also be calculated to test the reliability of the data collected during each round of the Delphi questionnaire (Chien et al., 2014). The accepted Cronbach's α value should be larger than 0.7.

In the first round of the Delphi, the main purpose is to collect experts' opinions on the comprehensiveness, practicality and applicability of the proposed framework. After round one, the initial criteria were revised according to the panellists' possible feedback. Factor with a median value less or equal to 3 and mean value smaller than 3.5 were removed; other factors were removed based on comment from participants. The removed factors after Delphi round one are shown below:

1. *Allies selection*: it aimed to have partners with the most adequate BIM capabilities on board for project completion with an expected target. Participants argued this was duplicated with the stakeholder involvement dimension. Additionally, the client would usually be responsible for this criteria;
2. *Procurement*: its purpose was to provide a direct answer to the general question of how the project can be done (Porwal and Hewage, 2013). 'Procurement' normally will start a tendering process. When the client is looking for a designer, the contractor or other supply chain partners, it would give client's requirement to the candidates. Therefore its focus is on the process of the work that is being done, as well as how the work should be delivered. In other words, procurement duplicates with terms e.g. contract, process, quality and data management aspects, hence it was removed from the framework.
3. *Framework interoperability*: this term turns out to be particularly important when considering issues related to sensor network (Shen et al., 2010). However this is mainly considered during the operational phase. Hence it received a lower credit from the panel.
4. *Notification*: aimed to inform stakeholders of information update or project schedule approaching. However, such function has already embedded within existing design platform as an attached function.
5. *Delivery*: the delivery of data in BIM circumstance is mainly through BIM server or cloud based, which mainly rely on high security of protocol. Hence participants believe this criterion overlaps the *access control*, *collaboration strategy* and *legal and contractual issues* etc.

One factor was added to the framework, based on feedback:

1. *Internal BIM pilot project*: before the actual deployment of BIM, it is best for BIM users to carry out several pilot projects with other partners (Howard and Björk, 2008, Porwal and Hewage, 2013, Tsai et al., 2014c). This could be conducted internally or small scale project, to simulate real situation and identify any potential risks and solutions (Zahrizan et al., 2013). This is especially necessary to get familiar with new form of business structure and process. This was agreed by all participants to improve the final project outcome, and most importantly, to increase their confidence and willingness during the transformation process.

The revised factor list was revaluated by panellists in Delphi round 2, which also allowed users to have a chance to reconsider their opinions in round 1 (Alyami et al., 2013).

5.3 Delphi round two

In Delphi round two, the questionnaire was modified based on the result in previous round. In the current round, only the name and criteria importance level judgement will be collected. Starting from the second round, all criteria will maintain a median and mean value above 3, since criteria lower than 3 have already been removed. All questions will be closed questions, where participants will only judge the importance level (by using 1 – 5 ratio scale). Other than the median, mean and Cronbach's α value, starting from this round, participant consensus will be calculated, which will be presented by IQR:

The workflow of the second round as shown in Figure 5-2 overleaf:

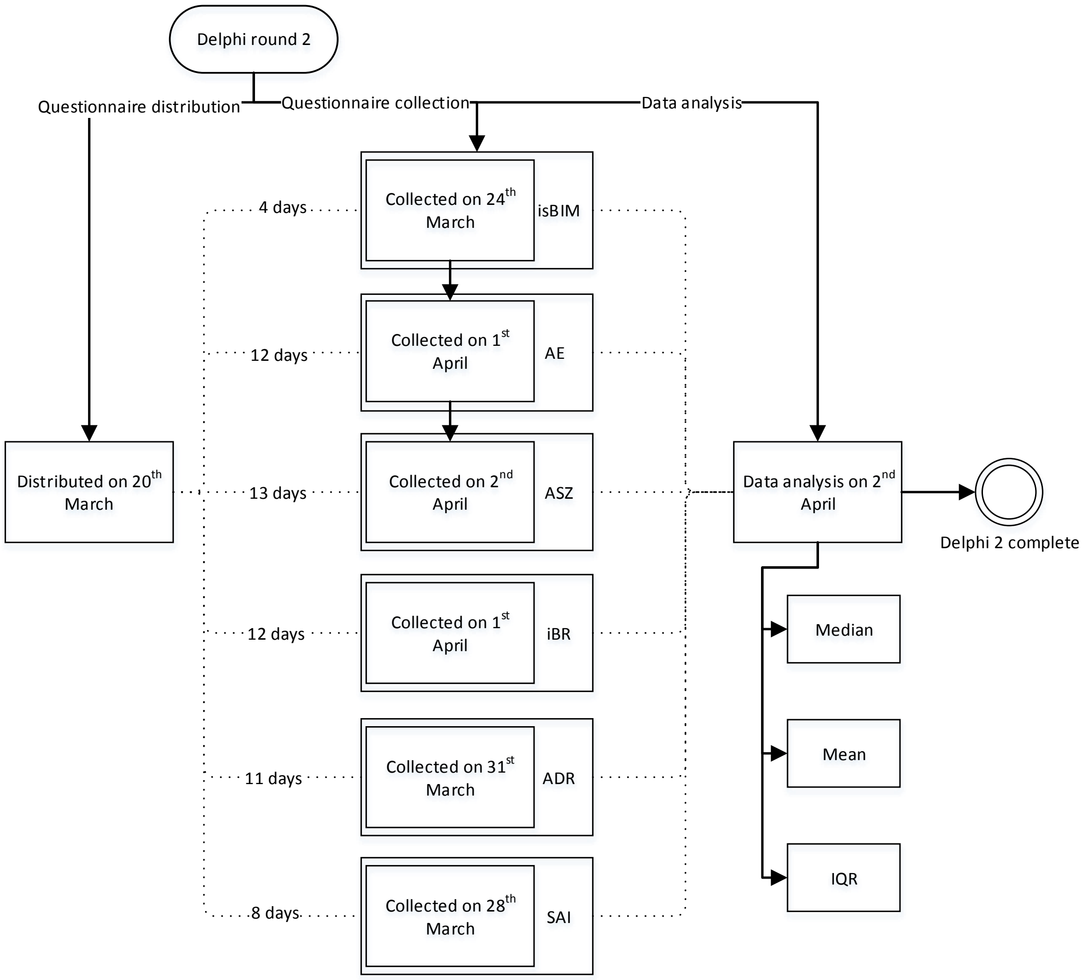

Figure 5-2 The workflow of Delphi round two questionnaire distribution and collection.

Delphi round two questionnaire has been send out on 20th March 2014 to all participants in PDF electronic format. All questionnaire has been sent back to the researcher within two weeks' time.

5.4 Delphi round three

The main objective of Delphi round three is to check if all participants have achieved consensus regarding to the importance of proposed criteria. The median value calculated in round two which was believed to present an average trend among all participants was used as group answer in this round, which was listed according to each individual factor. The purpose is to shift an individual's opinion to align with the group's answer. If consensus has been met, an IQR of less or equal to 1 will be obtained. If not, another round of Delphi questionnaire is needed.

Figure 5-3 below shows the workflow of Delphi 3, it was send out on 8th April 2014, and the data analysis process was conducted on 30th April 2014.

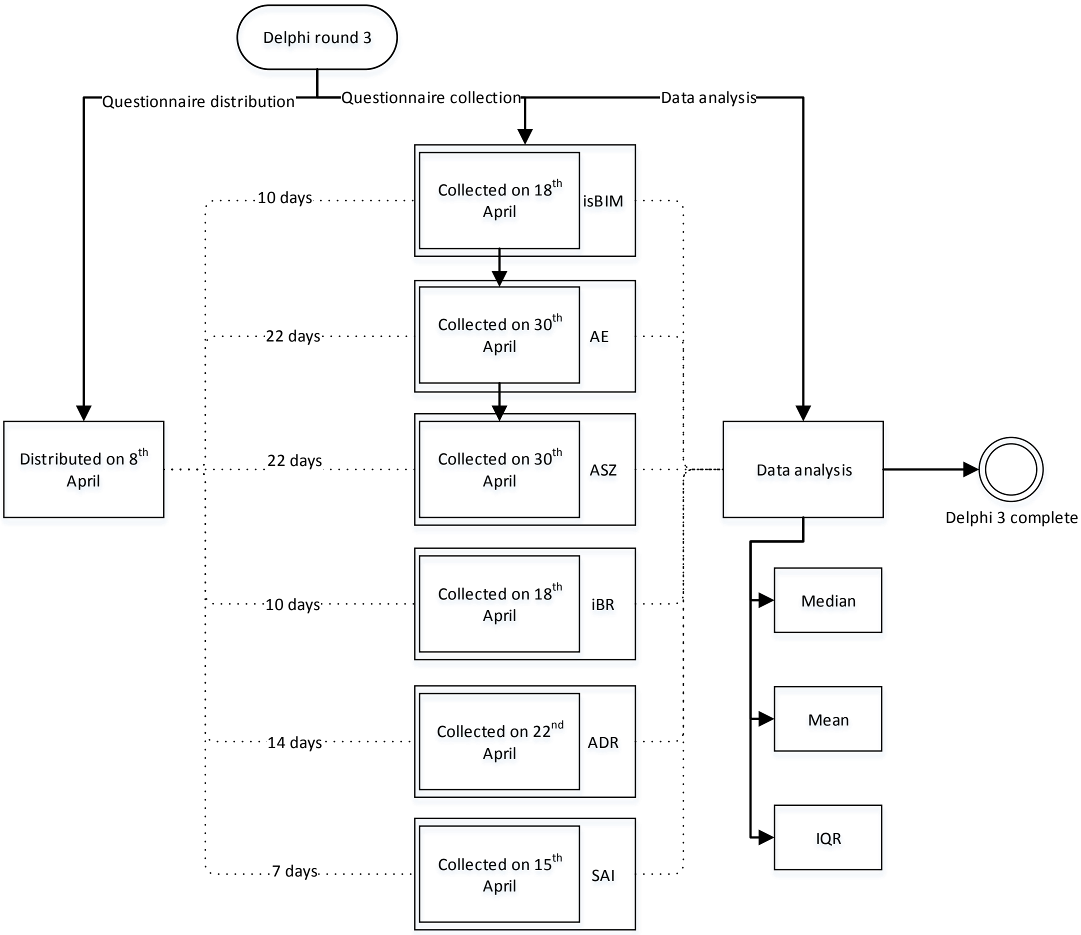

Figure 5-3 The workflow of Delphi round three questionnaire distribution and collection.

5.5 Delphi result

In this research, SPSS was used to proceed the data analysis session for all three rounds of Delphi: median, mean and IQR. The Cronbach's α value for three rounds are 0.973, 0.965 and 0.931 respectively, which is considered to be acceptable (Table 5-3 overleaf).

Delphi round	Feedback	Average/mean	Median	IQR	Cronbach's α value
1	Y	Y	Y	-	0.973
2	-	Y	Y	Y	0.965
3	-	Y	Y	Y	0.931
Tools	-	MS Excel/SPSS	MS Excel/SPSS	SPSS	SPSS
Accepted value	-	> 3	> 3	≤ 1.0	> 0.7

Table 5-3 Items to be calculated for each Delphi round

Table 5-4 below shows the comparison of participants among Delphi round 1, 2 and 3, as suggested by Sumsion (1998), responsible rate should be higher than 70% in each round.

Title	Delphi 1	Delphi 2	Delphi 3
Factor No.	74	70	70
Respondents No.	52	42	39
Response rate of current round	100%	100%	100%
Response rate to previous round	NA	80.77%	92.86%

Table 5-4 Delphi consultation1, 2 and 3 data comparison

Table 5-5 below shows the result of three round Delphi questionnaire, the median, mean and IQR of each criteria.

	D1		D2			D3		
	Median	Mean	Median	Mean	IQR	Median	Mean	IQR
Dimensions								
1 Project management	4	4.24	4	4.21	1	4	4.31	1
2 Data management	4	3.92	4	4.26	1	4	4.23	1
3 Application management	4	4.31	4	4.17	1	4	4.28	1
4 Organisational management	4	4.12	4	4.1	1	4	4.13	1
5 stakeholders involvement	4	4.27	4	4.14	1	4	4.38	1
1 Project management								
1-1 Project based BIM deployment	4	3.98	4	4.21	1	4	4.26	1

1-1-1 Administration deployment ： BIM EXP	4	3.81	4	4.17	1	4	4.28	1
1-1-1-1 Roles and responsibilities	4	3.81	4	4.07	1	4	4.36	1
1-1-1-2 Milestone and deliverable	4	3.61	4	3.79	1	4	4.23	1
1-1-1-3 LOD	4	4	4	4.21	1	4	4.36	1
1-1-1-4 Naming and folder structure	4	3.63	3	3.36	1	3	3.56	1
1-1-2 Technical deployment	4	4.04	4	4.07	1.3	4	4.23	1
1-1-2-1 Information interoperability	4	4.08	5	4.43	1	4	4.38	1
1-1-2-2 Framework interoperability	4	3.47	/	/	/	/	/	/
1-1-2-3 Technical issue	4	4.21	5	4.38	1	5	4.49	1
1-1-2-4 IT support	4	3.81	4	4.02	2	4	4.1	0
1-2 Allies selection	4	3.86	/	/	/	/	/	/
1-3 Legal and contractual	4	3.83	4	3.9	1.3	4	4.13	0
1-4 Collaboration environment	4	3.9	4	4.26	1	4	4.08	0
1-4-1 Collaboration strategy	4	3.59	4	4.21	2	4	4.08	0
1-4-2 CDE	4	3.49	4	3.69	1	4	3.95	0
1-4-3 Meeting	4	3.57	4	3.98	2	4	4.03	0
1-4-4 Notification	3	3.39	/	/	/	/	/	/
1-5 Process and Plan of work	4	4.04	4	4.167	1	4	4.128	0
1-6 Procurement	3	3.35	/	/	/	/	/	/
1-7 Change order	4	4.08	4	4.262	1	4	4.128	0
1-8 Resource allocation	4	3.94	4	3.88	1	4	4.03	0
1-9 Log management	4	3.59	4	3.64	1	4	3.95	0
1-10 Customer and quality assurance	4	3.76	4	4.26	1	4	4.15	0
1-11 Innovation	4	3.81	4.5	4.36	1	4	4.44	1
1-12 Project performance evaluation	4	3.89	4	4.12	0.3	4	4.08	0
1-13 Risk control	4	3.78	4	4.02	1	4	3.97	0
2 Data management								
2-1 Knowledge repository	4	4.12	5	4.4	1	5	4.51	1

2-2 Data requirement	4	4.1	5	4.38	1	5	4.62	1
2-2-1 Format of information	4	3.88	4	4.21	1	4	4.13	0
2-2-2 Information richness	4	3.8	4	4.29	1	4	4.18	1
2-2-3 Content requirement	4	3.82	4	4.17	1	4	4.18	0
2-2-4Information reliability	4	4.02	4	4.33	1	4	4.23	1
2-3 Data release	4	3.77	4	3.93	1.3	4	4.15	0
2-4 Data relationship	4	3.83	4	3.95	2	4	4.15	0
2-4-1 Versioning control	4	3.65	4	3.93	2	4	4.08	0
2-4-2 Referencing	4	3.61	4	3.71	1	4	4.03	0
2-5 Data security	4	3.9	4	4.05	2	4	4.1	0
2-5-1 Access control	4	3.78	4	3.83	1.3	4	4.03	0
2-5-2 Delivery	4	3.55	/	/	/	/	/	/
2-6 Data drop control	4	3.96	4	4.14	1	4	4.26	1
3 Application management								
3-1 Bidding/tendering document	4	4.11	4	4.19	1	4	4.23	1
3-2 Design stage support application	4	4.17	4	4.38	1	4	4.41	1
3-2-1 Energy and sustainability	4	4.06	4	4.02	2	4	4.21	0
3-2-2 Visualization	4	4.17	4	4.29	1	4	4.38	1
3-2-3 Integrated and coordinated design	4	4.38	5	4.55	1	5	4.56	1
3-2-4 Quality management/assurance	4	4.13	4.5	4.38	1	5	4.54	1
3-2-5 Quantity take-off	4	4.06	4	4.31	1	4	4.36	1
3-3 Construction support application	5	4.47	4	4.36	1	4	4.21	1
3-3-1 4D schedule management	4	4.28	4	4.26	1	4	4.21	1
3-3-2 5D budget control	4	4.3	4	4.33	1	4	4.26	1
3-3-3 Safety and environment	4	3.7	4	3.83	1	4	4.05	0
3-3-4 Construction project management	4	4.08	4	4.21	1	4	4.31	1
3-4 FM	4	4.17	4	4.19	1	4	4.15	0
3-5 Deconstruction	4	3.63	4	3.86	1	4	4.05	0
4 Organisational management								

4-1 Consistent vision	4	4.33	5	4.52	1	5	4.67	1
4-2 BIM performance evaluation	4	4.09	4	4.31	1	4	4.21	1
4-3 Business process reengineering	4	4.02	4	4.14	1	4	4.36	1
4-4 BIM expenses	4	3.58	4	3.81	1	4	4.13	0
4-5 Staffing skill, plan and training	4	4.1	4	4.14	1	4	4.26	1
4-5-1 BIM relevant material	4	3.56	4	3.74	1	4	4.13	0
4-6 Internal R&D	4	4.06	4	4.19	1	4	4.31	1
4-7 Internal BIM pilot project	/	/	4	4.07	1	4	4.1	1
5 Stakeholder involvement								
5-1 Owner/client	5	4.38	5	4.52	1	5	4.56	1
5-2 Designer	4	4.38	5	4.5	1	5	4.69	1
5-3 Contractor	4	4.21	4	4.17	1	4	4.21	1
5-4 Manufacture	4	3.66	4	3.93	2	4	3.97	1
5-5 Software vendor	4	3.9	4	4.14	1	4	4.21	1
5-6 Education	4	3.79	4	3.98	0.3	4	4.23	1
5-7 Government and public	4.5	4.35	4	4.12	1	4	4.36	1

Table 5-5 Median vs. Mean vs. IQR in Delphi round one, two and three

In Delphi round three, Majority criteria (61) has obtained an important level and 8 criteria were ranked as very important. Regarding to the consensus of each expert's perception respective to the each individual criteria, as shown in Table 5-6 overleaf, in column D2, 12 factors have a lower consensus which require one more round of questionnaire for improved consensus. 56 factors have an average consensus and only 2 factors received a higher consensus. In column D3, there are 27 factors received a higher consensus and the rest 43 factors have an average consensus. Therefore, three rounds of the Delphi study has adequately addressed the proposed research question: all concluded criteria are most suitable to Chia's context, and a fourth round of Delphi will not be necessary.

	Importance/consensus	Number of qualified factors in Delphi 2 (D2)	Number of qualified factors in Delphi 3 (D3)
Level of importance	1 (Not important)	0	0
	2 (Little important)	0	0
	3 (moderately important)	1	1
	4 (important)	59	61
	4.5 (between 4 and 5)	2	0
	5 (very important)	8	8
Consensus among respondents	<1 (High consensus)	2	27
	=1 (Average consensus)	56	43
	>1 (Low consensus)	12	0

Table 5-6 Consensus and importance comparison Delphi 2 vs. 3

Figure 5-4 overleaf shows the final list of criteria, including criteria that has been removed and newly added.

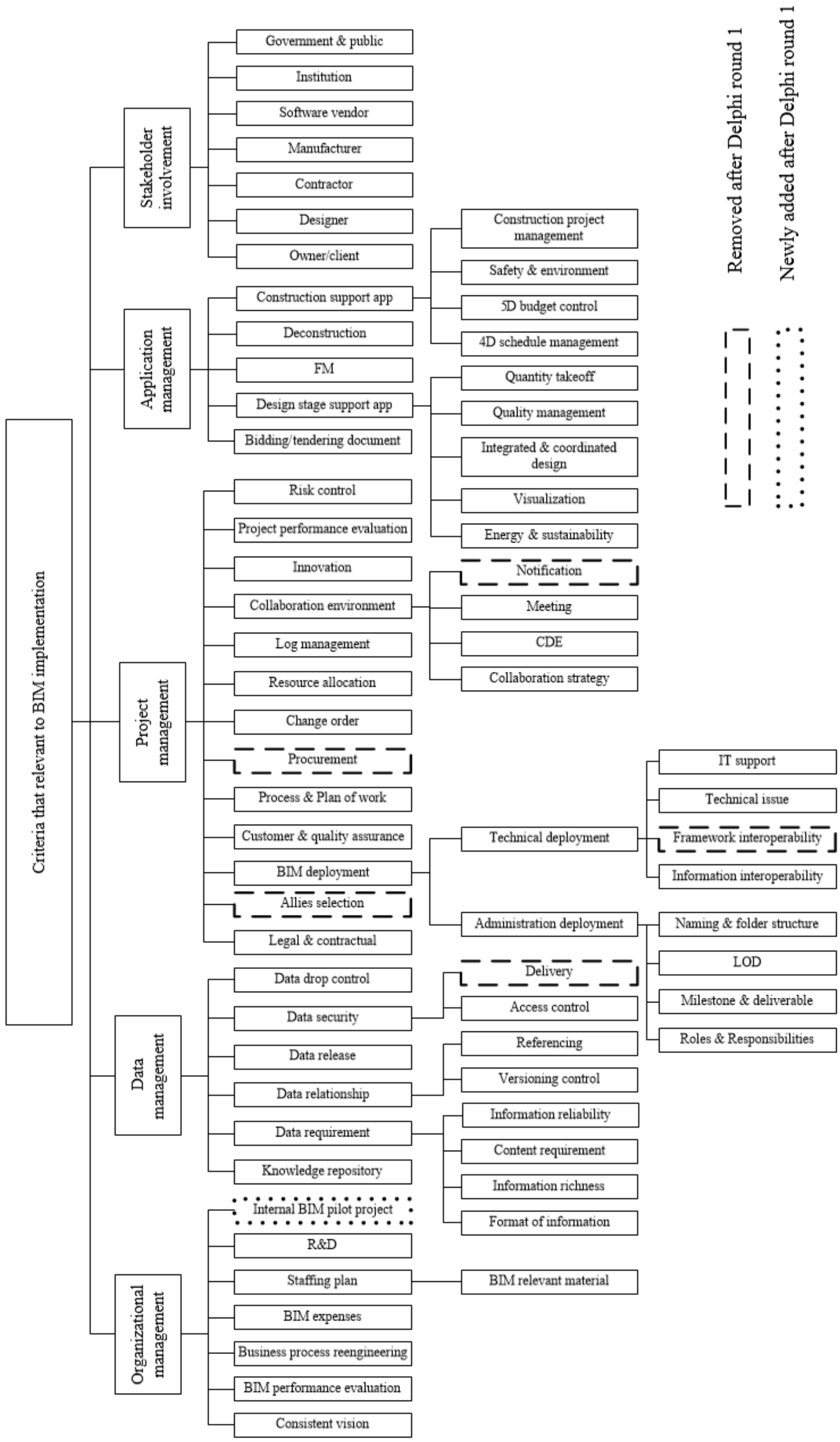

Figure 5-4 The proposed BIM implementation framework by Delphi study

5.6 Follow-up interviews & workshops

In order to enhance the rigour and confidence of the Delphi results, a follow-up interview and group meeting with each participant organisation was arranged. The subject was set around the proposed BiF due to geographical distances, interview sessions were only conducted with four organisations. For detail of participants' opinions please refer to Appendix M.

5.7 Summary

In this chapter, a consensus based group decision making method: Delphi method was employed to further refine the result from previous research steps in a specific context: China. 52 BIM users from management level to the technical level was invited from six Chinese organisations. In the first round of Delphi, participants have evaluated the importance level of each criteria and their feedback was recorded. Five criteria have been removed and one added after the first round. The second and third rounds of Delphi aimed to achieve a consensus on the importance the new criteria. After the third round of Delphi, a set of final criteria are important and also approved by all participants. The final BiF contains five dimensions and sixty five factors that most relevant to BIM implementation in China.

However, Delphi method only delivered a set of refined factors without ranking the proposed factors and as such do not possess any practical implementation value (Meesapawong et al., 2014). To complement this, the AHP method was adopted in the next step. AHP as a group based decision making method which will intake the criteria concluded from Delphi method, and create a strategic decision making tool for organisation to deploy BIM thoroughly.

Chapter 6. AHP based Strategic Decision Making for Organisational BIM Implementation

In the previous research, the applicability, effectiveness and the scope of the propose framework has been validated through a series of research instruments.. The final framework according to the objective of Delphi is suitable for long term decision making, prediction and most suitable for China .

In this chapter, the AHP as a follow-up research method will be employed to adopt the Delphi refined criteria in an AEC design organisation. A customised weighting system has been created to evaluate the BIM implementation in the organisation.

The first section of this chapter introduces how a hierarchy model was derived out of the concluded BiF from previous steps, which demonstrates the BIM implementation in a selected design organisation in China's AEC industry. Three focus schemes have also been proposed based on their current objectives. The results obtained from AHP method present a weighting system to be used for evaluation purpose, and the ranking order of three different focus schemes were also achieved.

The second section elaborates a validation approach which was designed to test the efficiency, effectiveness and user's satisfaction of the proposed BIM evaluation Framework (BeF).

Lastly, sensitivity analysis was conducted with the BIM manager in AS, based on the new developed BIM strategy. The entire conclusion of the six-step research are discussed in the next chapter (Chapter 7).

6.1 AHP application in ASZ

6.1.1 Analytical hierarchy model development

The purpose of this hierarchy model is develop a tool that can be used by the management team to make decision for BIM evaluation and strategic planning for future development. Required by ASZ, the decision making criteria demands a managerial perspective. The previously concluded BIM implementation Framework (BiF) (Figure 5-4) was used as a starting point and its original criteria need to be rearranged, as shown in Table 6-1.

Factor	Action	Reason
Sub-criteria under 'BIM deployment'	Removed	Factors either in a too detail level or in a technical perspective
IT support	Renamed 'Technical & tools requirement' as main criteria	The modified name are more suitable to the purpose from a managerial perspective.
Roles & responsibilities	Move under 'project dimension' as a main criteria	ASZ prefer to separate this from 'BIM deployment'
Sub-criteria under 'Collaboration environment'	Removed	Factors either in a too detail level or in a technical perspective
Criteria under 'Data management' dimension	Criteria under this dimension has been removed, 'data management' as a new main criteria under project level	Data management is a main aspect of BIM based project. Factors within the original dimension of Data management is very technical level.
Bidding/design/construction support application	Removed	Merged into other factors under the same dimension
Deconstruction	Removed	Merged into other criteria under the same dimension
Visualization, Integrated design	Combined & rename: '3D Visualization, coordination & clash detection'	To maximum reduce the number of sub-factors
Quality management/assurance	Merged into 'Customer and quality assurance'	Share same category
Construction project management	Removed	Merged into other criteria under the same dimension
BIM expenses	Merged into 'BIM performance evaluation'	Share same category
BIM relevant material	Merged into 'Staffing skill'	Share same category
Internal BIM pilot project	Merged into 'Internal R&D'	Share same category

Table 6-1 Actions to update previous concluded BIM implementation model to fit ASZ requirement

The final approved hierarchy framework as shown in Figure 6-1: four dimensions have remained as the second level of the hierarchy framework (H2). Level three (H3) comprises 21 criteria while level four with 14 sub-criteria. Moreover, the management team agreed that, in order to deploy BIM in a strategic way, at least one focus scheme was needed to guide the implementation direction. In ASZ's case, three focus schemes have been proposed and located at the last level (H5) of the final hierarchy framework. Their description details are shown below:

1. *Sustainability* is one of the most important topics in the global AEC industry (Wong and Kuan, 2014), especially in China (MOHURD, 2013). This could be achieved by improving environmental considerations (e.g. LEED, BREEAM etc.) to reduce energy consumption from the early design stage and focusing on the social welfare, to consider the environment, low carbon emission and eliminate unnecessary construction reworks during construction stage.
2. *Commercial value* aims to deliver the most profit and commercial value out of the services to the client and the products. It also enables convenient decision making for the client, especially in the preliminary design phase. Data-based project management also simplifies the developer's workflow. Moreover, marketing can now be integrated into design in a very persuasive way.
3. *Customer satisfaction:* The 'customer is the most important part of the production line' (Neave, 1987). As one of the tangible benefits of BIM (Arayici et al., 2009, Khosrowshahi and Arayici, 2012, Ali et al., 2013), a better customer appraisal scheme could maintain a good rapport with clients for repeated business: (a)for the investor: shorten the schedule and budget without any compromise; focusing on the quality of the product, such as energy simulation to achieve operating expenditure economize; (b) for the user: emphasize on the comfort experience of building users by helping perform wind and floor vibration test, for example.

The proposed three options will be the future focus scheme of ASZ, hence the impact of each of them towards each criterion will based on their current knowledge, understanding and attitude.

After the hierarchy model was established, pairwise comparison based on a ratio scale from -9 to 9 was conducted for priority calculation (SAATY, 1987). This included comparison of factors that under the same dimension and same main criterion (S1-S7 in Figure 6-1); and comparison of each objectives in respect to their impact towards each criterion within the hierarchy model.

Although it could be argued that the more items are compared, the more accurate result can be obtained, too many comparisons in the questionnaire could limit the quality and consistency of the result (Ozdemir, 2005).

6.1.2 Questionnaire design, distribution, collection & analysis

The data collection process was conducted by using questionnaire which collected two types of comparisons: (1) comparison between criteria and (2) the impact of each focus scheme towards each criterion.

At the beginning of the questionnaire, instruction was given to the users to guide them on how the questionnaire is going to be applied and how the AHP method works (Appendix J).

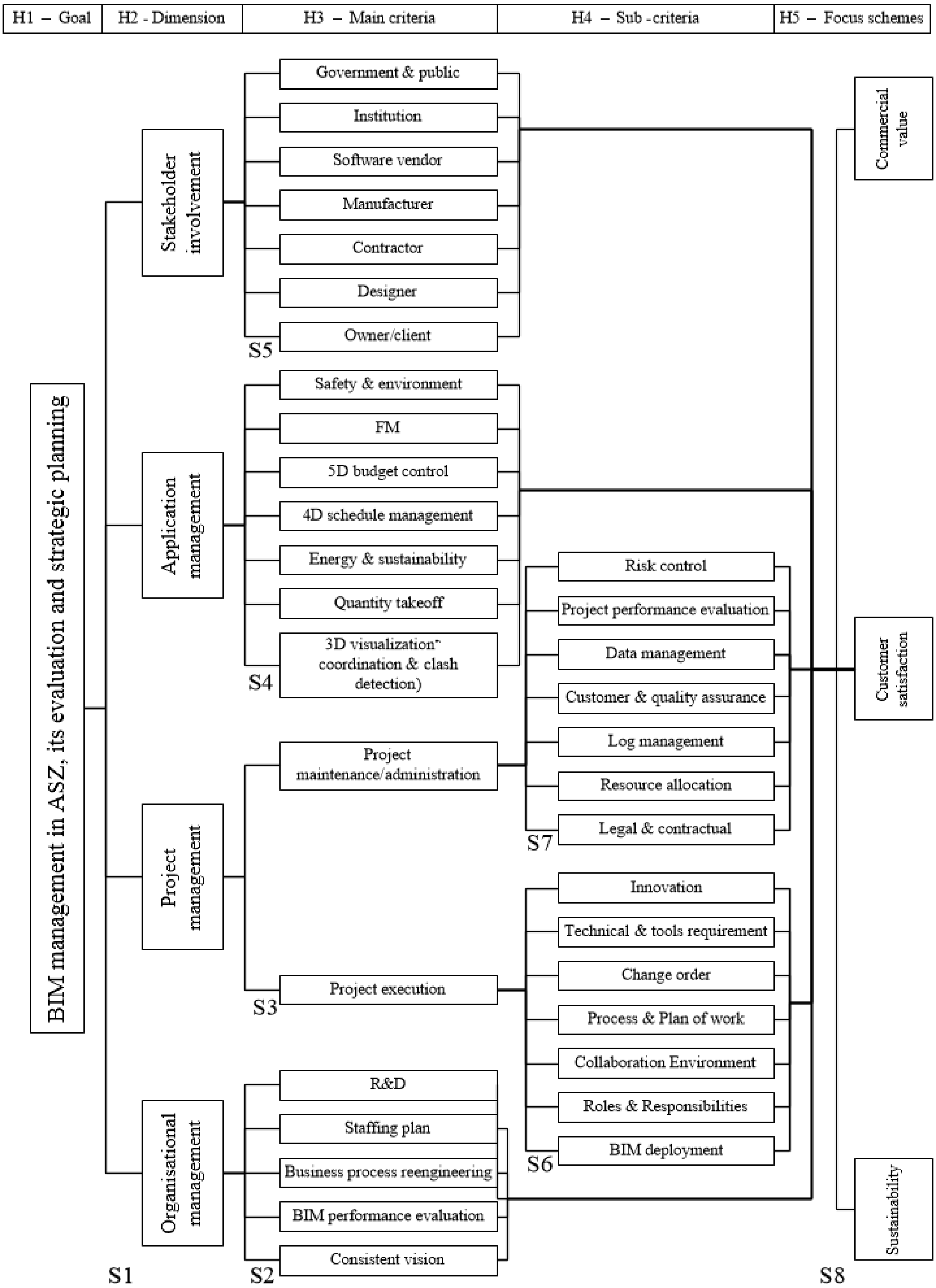

Figure 6-1 Hierarchy model for BIM implementation in SZA

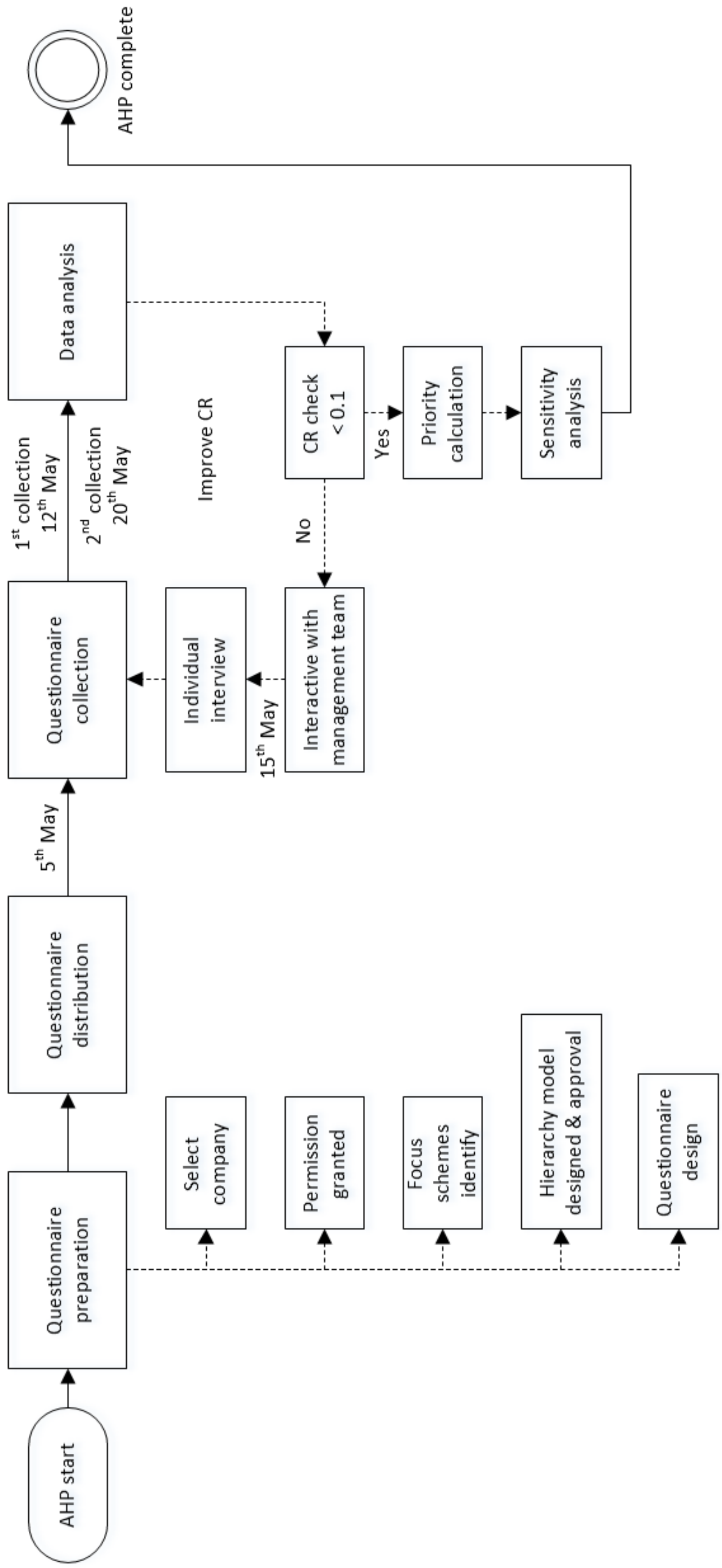

Figure 6-2 AHP questionnaire distribution and collection of data

The questionnaire was distributed on 5th May 2014, the first round data was collected on 12th May 2014 (Figure 6-2). Participants' background information are shown in Table 6-2 below.

The Descriptive statistics has been adopted to demonstrate participants' background information (Table 6-2), their experience, knowledge, professions, roles and qualification are considered for the most reliable and confidence data (SAATY, 1987, Tsai et al., 2014a). There is no architect involved, since: the architectural team is still in its early transformation stage in using BIM; in most cases, the client will appoint architectural team from another organisation.

	Categories	*Number of person / years of experience*
Gender	Male	7
	Female	3
Education info	PhD	1
	M.Sc.	6
	Bachelor	3
Professions background	Structural engineer	8
	MEP	2
BIM activity	BIM project manager	3
	BIM model manager	3
	BIM modeller	2
	BIM user	4
	BIM model coordination	1
BIM experience	> 6 (years)	1
	3-6	2
	2-3	3
	1-2	4

Table 6-2 Background information of AHP study participants

Consistency Ratio (CR) need to be checked (should not exceed 10%) before the actual priority calculation to ensure the reliability of the result collected from the pairwise comparison (Saaty and Tran, 2007). A lower CR value represents an obvious judgement of importance among various factors, while a higher CR implies that respondents have a less confidence on which is more important. A follow up individual interview was conducted to adjust the respondents' answer in order to make the CR value within the acceptable range but without reverse or change the respondents' initial intention. Table 6-3 shows AHP result after all CR has achieved a satisfied range (<10%), column 'factor PC' presents CR of factors under same dimension, while column 'options PC' present CR of different future objects' importance comparison in respect to each specific factors. The calculated values range from 9.6% to 0 which is accepted.

Hierarchy Level		Local (%)	Global (%)	CR value (%)	
				Criterion PC	Option PC
1	Goal: Future objective orientation of modern AEC organisation, a case study of ASZ	-	-	2.6	-
2	Project management	26.70	26.7	0.00	-
3	Project execution	37.1	9.9	0.3	-
4	BIM deployment	24.7	2.4	-	2.4
4	Roles & Responsibilities	9.2	0.9	-	3.5
4	Collaboration Environment	14.2	1.4	-	5.5
4	Process & Plan of work	16.1	1.6	-	2.6
4	Change order	12.9	1.3	-	7.1
4	Technical & tools requirement	10.8	1.1	-	3.3
4	Innovation	12.1	1.2	-	3.9
3	Project maintenance/administ ration	62.9	16.8	0.3	-
4	Legal & contractual	13.6	2.3	-	0.2
4	Resource allocation	12.8	2.2	-	7.5
4	Log management	7.3	1.2	-	1.2
4	Customer & quality assurance	18.6	3.1	-	7.2
4	Data management	9.5	1.6	-	7.1
4	Project performance evaluation	18.7	3.1	-	3.4
4	Risk control	19.4	3.3	-	8.1
2	BIM application	8.4	8.4	1.4	-

3	3D visualization, coordination & clash detection	7.8	0.7	-	4.9
3	Quantity take-off	18.3	1.5	-	2.9
3	Energy & sustainability	6.1	0.5	-	0.3
3	4D schedule management	23.5	2	-	9.6
3	5D budget control	29.6	2.5	-	5.3
3	FM	8.9	0.7	-	7.4
3	Safety & environment	5.8	0.5	-	6.1
2	Organisational dimension	50.6	50.6	7.6	-
3	Consistent vision	6.6	3.4	-	1.2
3	BIM performance evaluation	49.9	25.3	-	2.1
3	Business process reengineering	24.4	12.3	-	2.6
3	Staffing skill, plan & training	12.5	6.3	-	3.6
3	Internal R&D	6.7	3.4	-	1.7
2	Stakeholder involvement	14.2	14.2	2.3	-
3	Owner/client	35.9	5.1	-	2.7
3	Designer	14.3	2	-	4.8
3	Contractor	8.5	1.2	-	4.4
3	Manufacturer	7	1	-	6.7
3	Software vendor	5.3	0.7	-	5.3
3	Institution	5.3	0.7	-	4
3	Government & public	23.8	3.4	-	0.8

Table 6-3 Result of AHP study: global and local priority and CR value

6.1.3 The weighting system development

As shown in Table 6-3, general speaking, for the weighting system development, a higher global priority implies the specific criteria has a higher weight during the implementation stage, which will be considered to be implemented first when there is a resource constraint (Jung and Gibson, 1999).

The result shows the *organisational management dimension* received the highest priorities (50.6%) which is aligned with existing research findings (Penn State University, 2010). *BIM performance evaluation* (25.3%) received a high attention in their routine business activities to evaluate, control, predict and therefore to ameliorate the critical factors that affect project performance (Luu et al., 2008). Under BIM philosophy, conventional *business process* require *re-engineering* (BPR 12.3%) to integrate all business processes and projects within the organisation. Therefore, all individuals can get involved (Muthu et al., 1999) to improve strategy advantages. While managerial benefits still need to be quantified and clarified (Jung and Joo, 2011). Employee's awareness and confidence in BIM can be improved through *learning and training scheme* (6.3%) . Training will vary with the roles and responsibilities, and people in management position require a different and specific training (Singh et al., 2011). This will also enhance their competitiveness and enthusiasm in using BIM (Eadie et al., 2013).

Project management dimension received 26.7% of focus for BIM development, where *project maintenance/administration* (16.8%) received much higher attention than *project execution* (9.9%). With the consideration of the priority of *organisational* dimension, the numeric data obtained implies ASZ were more focused on the management development of BIM. *Risk control* (3.3%) can be further divided into two aspects: to reduce risk caused by adoption of new technologies e.g. software malfunction and information inaccuracy (Porwal and Hewage, 2013); and meanwhile to avoid project failure (such as ownership, legal risk (Mahalingam et al., 2010)) by relying on the new technology (Shafiq et al., 2013). *Customer & quality assurance* (3.1%) requires to reach the customer's satisfaction (e.g. Quality Insurance, schedule and budget control of the project) and other project performance evaluation perspective (e.g. environment, health and safety policy). Key performance indicators (KPI) are normally used to measure the *Project performance* (3.1%) of specific task of BIM throughout the project (Barlish and Sullivan, 2012).

Stakeholder involvement dimension received a slightly lower percentage: 14.2%. This reveals the value and effect of stakeholder during the building lifecycle still haven't reflected on the actual project. In the current AEC industry in China, the use of BIM is still the *client's decision* (5.1%), since the client is responsible for the selection of designer and contractor and has the pull to enhance the project performance as well as to pay the additional. *Designer* (2%) still dominant the BIM implementation process by starting the BIM model, and continuously inputting information into the model and passing the model to downstream users e.g. contractor. in order to improve industry-wide BIM competencies (Succar et al., 2013), all other partners should have their own roles therefore to form an entire BIM loop from a lifecycle view of building

(Mahalingam et al., 2010). Especially the involvement of *government* (3.4%) could propose associated policies, standards and guidelines for BIM, as well as mandatory requirement for all project to meet a certain level of BIM usage rate and sustainability rate. *Manufacture* (1%) provides BIM object library to designer to ensure the information within the BIM model is compatible and meets the requirement of the protocol (NBS, 2013a).

Application management receives the lowest attention from industry (8.4%). In one side, BIM technology development has been well developed (Jung and Gibson, 1999) therefore requires less resource input; in another side, specific application is more about technique adoption which has less influence in term of management e.g. modelling, simulation and analysis. The data shows ASZ currently has a focus on *5D budget control* (2.5%), *4D schedule management* (2%) and *quantity take-off* (1.5%). *4D schedule management* has a CR of 9.6%, which indicates participants believe it has a less obvious influence on various focus scheme.

6.2 BIM evaluation Framework (BeF) development & validation

6.2.1 BIM evaluation Framework (BeF) development

The AHP method delivered a weightage system, which identifies the priorities of each criterion in the analytical hierarchy model, as shown in Table 6-3. Therefore, an framework for BIM implementation evaluation during the project design stage is ready to be developed. Based on the aforementioned research steps, eleven criteria have been preliminarily concluded for BIM implementation evaluation:

1. Coverage: the assessment scope of the framework should focus on all the dimensions of BIM implementation instead of single aspect e.g. data management aspect;
2. Reliability: the assessment criteria adopted by the framework should come from a reliable source e.g. official BIM standards;
3. Applicability: the applicability of the selected assessment criteria should be proved by empirical evidence;
4. Qualification: the selection of BIM users for criteria verification should follow certain requirements e.g. disciplines, experience in BIM etc.

5. Consensus: the group consensus for each assessment criteria should be achieved;
6. Weightage: the weight of each factor should be calculated scientifically and should be obtained based on all project stakeholders' opinions;
7. Prioritisation: the criteria should be prioritised and the sum of all weights should be 1, instead of using an average value or a simple ranking order to represent their priority;
8. Focus scheme: the development of the framework should consider the organisation or project's focus scheme;
9. Ranking order: the ranking order of each focus scheme should be obtained;
10. Impact: the impact of each criterion on various focus schemes should be clear (e.g. either a positive or negative influence) and therefore improve the organisation's attitude on the selected focus scheme;
11. Benchmarking: the framework should have the potential to be developed as a benchmarking method for comparison among organisations.

In order to develop an evaluation framework, the following steps have been followed in this research:

1. Based on the management team's requirement, the original BiF had been modified and all criteria contained in the hierarchy model used in AHP step was more about the managerial perspective. However, the use of BIM in project is multi-dimensional, which includes all aspects including detail level such as technical implementation. Hence a connection between managerial criteria and other criteria as included in the final BiF. The weightage to every single criterion was allocated. However, there were some changes on the criteria based on the demand from ASZ:
2. To quantify each criteria into several scales/levels, to describe the progressive improvement of BIM usage from non-BIM to collaborative BIM of that particular criteria. The weight of each criterion will be equally assigned to each level it can be divided.

The proposed BeF has the following applications:

1. To be applied by project manager or BIM strategist at the **beginning of the project** to assist with decision making and BIM implementation strategy based on the prioritised criteria:
    - To decide priority of potential BIM applications; and consider their interrelationships and impact to client's business case in long term;
    - To define responsible party and deliverables etc.;
    - To assess stakeholders' BIM competencies and available resources;
    - Predict risk and revenue etc.
2. To rapidly review the ongoing project's condition and come up with the best option to optimise the follow-up process and activities **during the project lifecycle**.
3. The closing process of a project will guarantee the formalised acceptance of a project or a certain phase and lead to an orderly end (Kwak and Ibbs, 2002). Kwak and Ibbs also argue it would be useful to develop a systematic lessons learned documentation, therefore the developed BeF could perform a **closing inspection** to discover weak and strong points from the completed project for future improvement.
4. To evaluate the best BIM based project that a company has completed, therefore to obtain its BIM capability.
5. Designer prequalification decision making process (Russell and Skibniewski, 1987, Porwal and Hewage, 2013) can be performed: the client will assess the candidates' (potential design team) BIM capability by using the proposed BeF, therefore to eliminate less favourable candidates: those who has received a relatively low evaluation result (Sonmez2 et al., 2002, Sebastian and van Berlo, 2010).

The developed assessment framework has been partially shown in Figure 6-4. The assessment framework was developed by programming in Microsoft Excel (detailed in Appendix N).

Column A-C displays all assessment criteria; their associated definitions are displayed in column D-E, to ensure there is a clear understanding regarding each specific factor (Jung and Gibson, 1999).

The maturity model requires to have a set of incremental levels to represent the involvement of BIM (Succar, 2009b). According to some existing literature (Rezgui et al., 2013, Succar, 2009a, BIMIWG, 2011), the application of BIM can be categorised into three levels:

1. Level 0: traditional CAD based approach;
2. Level 1: mixed 2D CAD and BIM approach;
3. Level 2: fully collaborative BIM approach.

In the proposed BeF, it is also believed that the transformation from traditional to BIM based practice requires a progressive transformation, therefore, this framework also presents how incrementally traditional practice could be transferred into BIM (Miettinen and Paavola, 2014). Each criterion has been divided aligning with these three levels according to their own character: column F presents non-BIM was involved during the practice; column G to J present a progress improvement of BIM used in practice till collaborative BIM. Different category in column 'Maximum level' indicates the maximum scale that a criterion could meet, where 'Current Level' and 'Target Level' identify project's current and target BIM usage level, this could allow the application 1 as shown in Figure 6-4. In other cases, they can be replaced by project 'A', 'B' and 'C' for comparison between projects.

BIM is still under development, it is impossible to predict how BIM will develop in future, therefore there is no upper boundary limit for BIM level (Cui, 2012).

As shown in Figure 6-3, User will simply input their appropriate maturity level under 'User fill in' column, their weight can be automatically calculated and the summation can used for comparison.

For example, the full point for criterion 'Milestone and delivery' is 0.48: capability level 0 will receive 0 point, level 1 will receive 0.24 points and level 2 will receive 0.48. By selecting level '1' or level '2' in 4P and 4S in the Excel table, 0.24 or 0.48 will be obtained to represent the capability of BIM for this particular criterion.

With such self-assessment framework, BIM user could identify their current performance for continuously improvement through an easier, efficient and consistent approach . In addition, the steps toward collaborative BIM have been elaborated from column F to J to guide user to move for the next level of BIM using.

Row	Plan	Deployment	Factor (selected for China Context only)	Description	Level of BIM capabilities: 0	1	2	3	4	Maximum level: Proficiency level	Maximum weight available (Based on China context)				Current Level: Proficiency level (User fill in)	Sub-factor weight	Factor weight	Target level: Proficiency level (User fill in)	Sub-factor weight	Factor weight
3	1.Project management related factor																			
4	1-1 BIM Deployment plan	Administration deployment	Milestone and deliverable	*Project delivery schedule required to be clearly defined and followed by all project participants e.g. exact time and data format need to be*	Project delivery information are only briefly mentioned: only date has been mentioned	Project delivery information are clearly mentioned with a format & date requirement	Project delivery clearly defined & executed throughout the entire project with mandatory enforcement by manager			2	2.400	1.440	0.480		1	0.240		2	0.480	
5			LOD	*Level of Detail describes the amount of information delivered by the model in order to fit the purpose of a specific drawing*	No LOD has been defined or used	LOD defined but limited to certain project stages	LOD has been extensively utilized throughout the entire project	LOD has been aligned with industry standards e.g. MVD & IDM and additional customized requriement		3			0.480		1	0.160		2	0.320	
6			Naming and folder structure	*A well organised and followed naming & folder convention/nomenclature could improve working efficiency*	No naming convention has been adopted	Naming convention utilized for certain area of the design work and business documentation	Naming convention utilized throughout the entire project, for all business documentation, by all parties			2			0.480	0.240	1	0.120		2	0.240	
7					No folder structure has been adopted	Folder structure has been adopted by part of the project teams	Folder structure has been adopted by all project teams			2				0.240	2	0.240		2	0.240	
8		...oyment	Information interoperability (e.g. IFC)	*An open standard for compatible collaboration environment is the pre-requisite to adopt BIM, and it encourages the integrated design process among all stakeholders*	No compatibility between platform or teams was considered	Limited interoperability has been achieved by adopting tools from the same vendor e.g. the use of COBie	Full interoperability was achieved by machine to machine linkage or limited use of IFC	Full interoperability has been achieved by using IFC throughout the project lifecycle		3			0.480		1	0.160		3	0.480	

Figure 6-3 Example of proposed BIM evaluation Framework (BeF)

The final credit gained will be accumulated both at the end of each dimension and the whole assessment framework. This allows the result to be reviewed by different beneficiaries, such as the management team, project team and stakeholders etc. to point out existing weakness for an overall improvement.

6.2.2 Validation result & analysis

Comparison among practical projects

Projects A-E result analysis

There are five projects were selected for the evaluation stage (Table 6-4). The evaluation was conducted at the end of 2014, projects (C, D and E) completed in early 2014 and late 2013 have been defined as 'recent completed' project. Projects A, B and C were complete by the same team. Based on the hypothesis made before, their BIM maturity and performance should be continuously improving along with time.

Projects	Team	Design completed time	Expected result	Actual BIM level	nD BIM Model quality	Actual project performance	Project character
A	1	2009	Lowest	7.644%	3.14	46	Small scale project
B	1	2012	Low	10.894 %	3.43	48	Small scale project
C	1	Early 2014	High	31.954 %	5.86	66	Landmark, large scale project, high requirement for BIM performance from client
D	2	Late 2013	High	15.44%	4.57	54	Tight budget and time, limited human resource
E	3	Late 2013	High	41.581 %	6.57	64	New management system

Table 6-4 Validation result of project A-E

Project A was designed in 2009 for a simple office building in Shen Zhen. As one of the earliest BIM based project, its project outcome and BIM usage level are the lowest in all five projects as expected in the framework.

Project B was designed in 2012 for an ultra-high rise finance centre, including hotel, luxury flat, shopping centres and building office in Shen Zhen, its project outcome and BIM maturity is higher than project A.

Project C was designed in early 2014 for a mixed shopping mall, office building, hotel etc. in Cheng Du. Its BIM usage level and project outcome is much higher than project A & B.

Project D was designed in late 2013 by team 2 for an R & D type of office building. As one of the recent completed project, its BIM usage level and project outcome should be similar to project C, but it is much lower although it is still higher than Project B.

Project E was designed in late 2013 as well for super high rise office building, its BIM usage level and project outcome have received the highest among all five projects. All these comparisons demonstrated that the test results from the developed framework aligns well with the expected outcomes.

<u>nD BIM model comparison</u>

In order to reveal how well the criteria included in the BeF have been carried out during the actually design process, hence the comprehensiveness and operation of the nD BIM model of selected five projects have been analysed.

The result presented in Table 6-5 overleaf shows a similar trend to the BIM usage level assessment that achieved in each project, this proved the maturity from BIM manager's perspective also align with individual's BIM proficiency.

Items	A	B	C	D	E
LOD (lifecycle adoption)	4	4	6	4	7
Naming/folder structure	2	4	6	5	7
Compatibility	6	6	8	6	6
Information richness	3	3	5	6	4
4D BIM	2	2	6	2	6
Data access/modification right	3	3	6	4	8
Customized template/library component	2	2	4	5	8
Average	3.14	3.43	5.86	4.57	6.57
1-10: 1 = poor; 10 = good					

Table 6-5 nD BIM model comparison among project A-E

Project performance comparison

In order to compare the BIM usage level and project performance in the same project, a list of Key Performance Indicators (KPIs) have been selected from literature, discussed and approved by Arup management team to represent the project's performance in four aspects: profit, quality, efficiency and client's satisfaction, as shown in Table 6-6 overleaf.

Category	Items	Formula	Replacement	Sources	Availability
Profit (of project: design work in this case)	Profitability (BIM)	Profit/revenue %	1-10 scale	(ONS, 2010)	Yes
	Profitability (Overall)	Profit/revenue %	1-10 scale		Yes
	BIM ROI (coordination/cost estimation)	BIM net saving/BIM cost%	Total save-total cost (1-10)	(Giel et al., 2013)	Yes
Quality (Ali et al., 2013) (of the developed nD BIM model and final product delivery to the client)	Model value to cost-estimation	1-10 scale	-		Yes
	Rework	Rework cost/total cost%	-	(Ali et al., 2013)	NA
	Quality management system	1-10 scale	-	(Luu et al., 2008)	Yes
	Contract & legal disputes	1-10 scale	-	(Ling et al., 2009)	Yes
	Environment & sustainability	1-10 scale	-	(Najafabadi, 2013)	Yes
	Product defects	1-10 scale	-	(ONS, 2010)	Yes
Efficiency (work done in unit time)	Efficiency ratio	Cost/revenue %	-	(Yu et al., 2007)	NA
	Design/construction cost ratio	(Actual-estimated cost)/estimated %	-	(Luu et al., 2008)	NA
	Design/construction schedule ratio	(Actual-estimated time)/estimated %	-		NA
Client's satisfaction	Service satisfaction	1-10 scale	-	(Luu et al., 2008, ONS, 2010)	Yes
	Product satisfaction	1-10 scale	-		Yes
	Customer's repeatability	1-10 scale	-	(Ali et al., 2013)	NA
	Innovation	1-10 scale	-	(Najafabadi, 2013)	Yes
1-10: 1 = poor; 10 = good					

Table 6-6 Key Performance Indicators for project A-E

The selection of KPIs should follow several rules: clear, measurable, and relevant to the measure object etc. However, some of the above-mentioned KPIs are still not practical in reality.

-KPIs that are relevant to profit are hard to track or link to BIM. Since there is no record to clarify the exact amount of cost for BIM hardware, software expenditures and training etc. as those expenses are one time capital cost which can have influence in more than one project.

-Return on investment (ROI) cannot be obtained due to commercial sensitivity. The calculation of ROI is also complex, it involves land value, various regulatory processes approvals, and other costs.

-The definition for rework is hard to separate from normal tasks, as this was not recorded during practical design work. For rework during construction stage, it will only be managed by contractor.

-The efficiency and what has been saved or improved by BIM during the design or construction stage is hard to be quantified. Based on the quality, experience, maturity of the ability of the team and management approach, there will be a downside at the initial implementation stage, however, in long term, BIM could help to achieve a better planning during design stage, with a better coordination performance.

The 0 - 10 rating scales were adopted where 0 presents BIM has no benefit in the adoption of this particular aspect, and 10 presents an extremely satisfied level. Table 6-7 demonstrates the result collected from BIM manager in ASZ.

Items		A	B	C	D	E
Designer perspective	Profitability (BIM)	1	1	2	2	1
	Profitability (Overall)	1	1	3	3	5
	BIM ROI (Coordination)	0	0	2	3	1
	BIM ROI (Cost estimation)	1	1	5	3	1
	Model value to cost-estimation (Architecture)	1	1	1	6	6
	Model value to cost-estimation (Structure)	1	1	6	7	8
	Model value to cost-estimation (MEP)	1	1	1	7	8
	Model value to cost-estimation (4D scheduling)	1	1	5	4	4
	Quality management system	1	1	6	6	6
	Contract & legal disputes	1	1	7	7	8
	Environment & sustainability	1	1	1	0	4
Client perspective	Product defects	9	9	7	8	7
	Service satisfaction	8	9	8	8	8
	Product satisfaction	10	10	9	8	8
	Innovation	6	5	8	6	8
1-10: 1 = poor; 10 = good						
Total		43	43	71	78	83

Table 6-7 Project performance comparison for project A-E

Based on the hypothesis, project A & B should have a lower satisfaction in all aspects compared to project C, D & E. however, this is not the case in some of the KPIs as shown in Table 6-7 above. Project A & B are simple structure buildings, which is easier to be delivered and meet customer's requirement for a higher satisfaction. Moreover, during the early adoption stage of BIM in China's construction industry, the use of BIM in project A & B has just started and under an exploration stage. The expected BIM achievement and functions in business activities were simple and easier to be achieved (for example, the main objective is to generate 3D building model). However, in a later stage, when the project C, D and E was conducted, client's knowledge of BIM has improved according to public reports from more developed countries such as US e.g. (McGraw-Hill construction, 2008, McGraw-Hill Construction, 2009a, McGrw_Hill Construction, 2012). But due to the limited development of BIM in China, client always expect more from the designer and contractor, but which could not meet their expectations. Therefore a relatively low satisfaction level has been achieved.

The total value achieved in Table 6-7 shows there is a clear improvement in term of project performance in its all aspects (profit, quality, efficiency and customer satisfaction) with the progress made in BIM in reality.

Factors that affect BIM usage level

Based on the BIM usage level evaluated by the proposed BeF, discussion was conducted with BIM manager in ASZ, reasons that could affect BIM usage level have been concluded.

In the current China AEC industry, the traditional project management approach, people's professional cultures and working environment are very difficult to be changed towards BIM compliance, which have been believed as one of the main challenges for using BIM. What's more, there is no simple, quick and effective solution for this. Instead of replace the traditional approach completely, it is better to embed BIM concept into the existing method and process, therefore to facilitate further development within the local context. However, this causes majority of the project are still following a traditional 2D CAD based approach, while BIM is only used for specific purposes, e.g. 3D BIM models are created for visualization and clash detection only, information within the BIM model has not been reused by other stages; The contractors still follow 2D based construction drawings, while the BIM model received from designer are mainly used for 4D based scheduling to support construction management approach.

At the beginning years of BIM adoption, technology was the main focus, hence project A & B were focusing on 3D modelling and coordination among disciplines (Brynjolfsson, 1993, Jung and Gibson, 1999). Other aspects of BIM e.g. management, organisational & stakeholders involvement etc. was not considered in those projects which therefore led to a lower BIM usage level (5.9% & 9.2% respectively); project C is an iconic large-scale mixed-use projects with multiple functions. As one of the most recent projects, industry's awareness on BIM has been largely expanded. The client had a higher requirement on the multiple aspects of BIM adoption, such as project management aspect, coordination and collaboration among stakeholders, therefore a higher BIM maturity level (30.3%) was achieved.

Management paradigm

The adoption of BIM and its usage level is also based on the project manager's individual method, as well as available resources. Project D has a tight project schedule and labour resource, where only one engineer was working on a single BIM model. Moreover, the project manager's own management paradigm stayed more with traditional approach. Therefore, only technological aspect of BIM was adopted (e.g. 3D visualisation, clash detection and 4D BIM etc.), which is similar to project A & B. However, those criteria have not been particularly emphasized in project D, such as *BIM deployment* and industry's awareness (*stakeholder involvement*), still received a higher BIM level compared to earlier project. Therefore, compared to project D, a lower level of BIM level was achieved (14.773%) but still higher than earlier projects A & B.

Starting from project E, a new systematic method of BIM management was adopted and a much higher maturity was achieved (39.998%). The method includes: development of standardised template, standards, continuously improved repository and operation process etc. It largely reduced the requirement on individual's BIM competency and improve the quality of collaboration between different parties (e.g. visualise all building's information). From the organisational level, their BIM implementation has standardised the BIM adoption procedures in its project hence the organisation's management maturity has been increased.

Contractual and legal aspect

The BIM related profit issues among disciplines have not been clearly defined in the current contract/legal practice, which is another barrier for BIM adoption throughout building lifecycle. In the case of Arup ShenZhen, the client normally has a contract relationship with designer and contractor individually, however, there is no contract relationship between designer and contractor. Therefore without a contract framework (e.g. (ConsensusDocs, 2011)), dispute and potential risk could happen especially when there is a need for collaboration and coordination with other partners in BIM implementation.

Therefore, the selection of BIM function, or the priority of key implementation area of BIM is largely based on the lifecycle operation of the project, management requirement, project's character, client's need etc. Based on the vertical and horizontal comparison among those five projects, it proved the proposed BeF has a good correlation to the final project outcomes, e.g. where a higher level of evaluation result suggests a better project outcome. In another word, adopting this framework can improve the BIM implementation level and ultimately project performance.

Comparison with existing methods

In order to validate the accuracy of the BeF, existing assessment tools (e.g. I-CMM, BPM, OBIM & ABMF in Chapter 2) have also been used by the BIM manager to evaluate all five projects in previous step. As shown in Table 6-8 below, results obtained from all five applied assessment methods provide a similar trend. As discussed, existing assessment methods focus more on a single aspect of BIM implementation, so by calculating their average, it could provide a more comprehensive result considering all aspects. The comparison between their average values and the result obtained by BeF are shown in Table 6-8 and Figure 6-4 overleaf.

All result shows the proposed BeF is effective and efficient and meet user satisfaction.

Project	Result					
	Proposed tool	Other existing tools				
		I-CMM	BPM	OBIM	ABMF	Average
A	7.644%	15.5%	34.4%	4.4%	27%	19.6%
B	10.894%	23.7%	37.5%	6.7%	27%	23.7%
C	31.954%	44.8%	62.5%	11.1%	40%	39.6%
D	15.44%	39.5%	31.3%	13.3%	33%	29.3%
E	41.581%	35.7%	43.8%	15.6%	35%	32.5%

Table 6-8 Project A-E results comparison between existing methods' average value and BeF

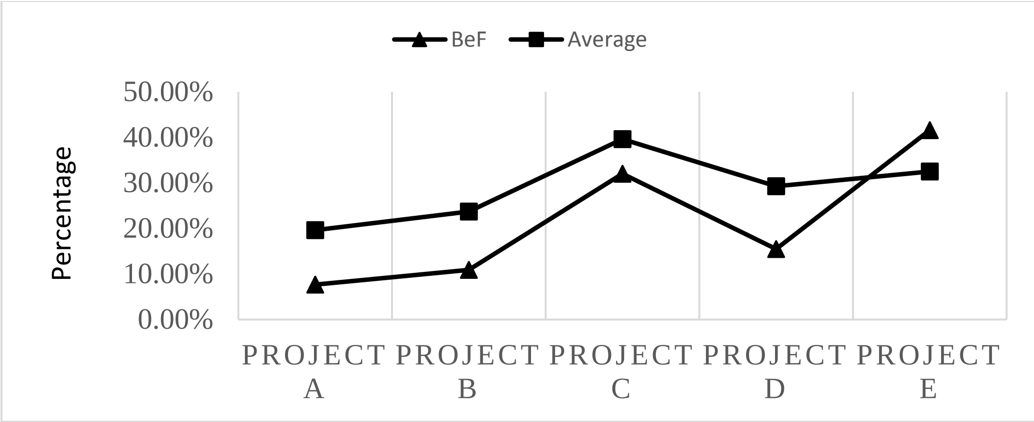

Figure 6-4 Project A-E results comparison between existing methods' average value and BeF

User's feedback

It takes about 30 minutes for the BIM manager from ASZ to fully understand and digest the concept, definition of criteria proposed, the assessment framework's logic structure and intention. The developed BIM evaluation framework covers major BIM implementation areas during the design stage. Moreover, BeF has fully considered all stakeholders' involvement, this is the very key for BIM implementation in most cases. The user's feedback is concluded as below:

1. The proposed framework can effectively assist project manager for BIM strategy planning: business activities can be conducted according to their priorities, wise decision can be made when there is a resource constraint for a higher level of BIM implementation;
2. BeF illustrates all important implementation criteria to all stakeholders, the evaluation process was conducted under a transparent circumstance, and helped to facilitate comparison and improvement.
3. Proposed BeF has displayed all criteria effectively in a structured and systematic way which can be used to evaluate and monitor business improvements (BIMtaskgroup, 2012);
4. The framework can be used to evaluate whether or not the organisation is ready or qualified for BIM based project, especially on how good or bad for their BIM implementation capability.
5. The proposed framework can also be applied for education/training purpose, to give a general background of BIM concept to the trainees, as well as their

importance to the various objectives. Based on the weight of each criteria, training and education plans can be produced to improve the operational proficiency, BIM usage level and project performance.

6. The assessment framework is based on Microsoft Excel, it is easy to use, without additional training or hardware requirement, or constrained by internet or complex installation process;
7. The assessment process can be performed by any individual employee or a management team;
8. The proposed assessment framework can be easily modified and adapted for changed context, e.g. add or remove criteria, change of weightage system or add or remove future objectives for specific scenario (Du et al., 2014, Wang et al., 2005).

6.3 Sensitivity analysis

6.3.1 Ranking score of focus schemes

As included in the AHP questionnaire, the second section compared the impact of each focus scheme towards all criteria within the BeF. There are sixty five criteria in total, which generates sixty five questions and matrices. The weight of each focus scheme can be obtained by calculating the eigenvector of each matrix. In total, sixty five set of weight for each focus scheme can be generated. In order to obtain the ranking score of each focus scheme in ASZ, the composite weight was used. This can be contained by using the weight of each focus scheme multiplies the global priority of each corresponding criteria, and add with other sixty four pairs.

In a similar fashion, the ranking order of future objectives (Table 6-9) was also obtained from MIR, the composite value shows ASZ has an emphasis on the creation of commercial value (59.13%) outstripping the other two. Also there are less resources allocated on other alternatives, especially for development in sustainability (14.48%). Thus the result shows there is a stable emphasis in commercial value for their current development (Zhu et al., 2005).

Alternatives	Weight				Total (%)
	Project management	Organisational management	BIM application in lifecycle	Partner involvement	
Commercial value	16.22	29.64	5.16	8.11	59.13
Customer satisfaction	6.82	13.35	2.24	3.99	26.40
Sustainability	3.69	7.65	0.99	2.15	14.48
				Total:	100

Table 6-9 Ranking order of future objectives & contribution from each dimension

6.3.2 New priorities & strategy

Besides commercial profits, ASZ also needs to consider the need from local communities, the development for human society and global competitiveness, and more sustainable and user oriented products and services. Hence it is necessary for ASZ to shift their existing priority to have more emphasis on sustainability. Dimensions and factors contained within the proposed hierarchy model are interconnected and closely related to each other. In addition, due to the summation of each criterion's weight (in percentage) is equal to 1 (100%), improvement of any factor's weightage could result in reducing others'. Hence it is necessary to reveal the impact of each criteria to each focus scheme: either there is a positive impact or negative impact, which can be improved or reduced accordingly.

Based on the AHP questionnaire collected from ASZ, MIR has calculated the relationship between a specific criteria and focus schemes. For example, MIR obtained an influencing chart for criterion: e*nergy & sustainability* (E&S) regarding three alternatives:

Energy & sustainability (%)				
Alternatives	Minimum 0	Current 6.1	Maximum 100	Impact
Customer's satisfaction	26.39	26.40	26.50	0
Sustainability	14.34	14.48	16.61	0.0227
Commercial value	59.27	59.13	56.88	-0.0227

Table 6-10 Example of sensitivity analysis: impact of *Sustainability* towards Focus schemes

As provided from Table 6-10, the current global priority of E&S is 6.1%, by improving its global weight, there will be a 0.0227% improvement for every 1% improving. The tendency are generated from MIR as Figure 6-5 below:

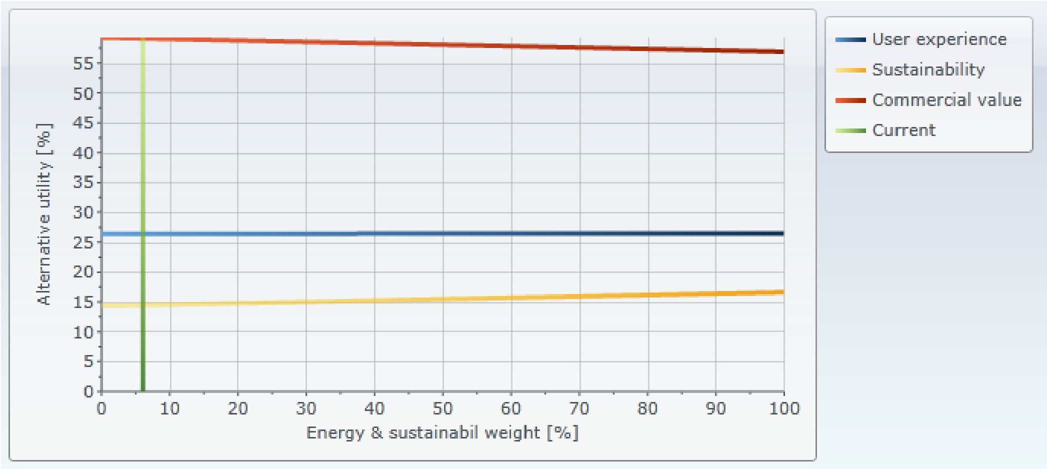

Figure 6-5 Example of sensitivity analysis: impact of *Sustainability* towards Focus schemes

As shown in Table 6-11 below, a positive value means an incremental trend, while a negative value means a reduction trend to that focus scheme. The perturbation to the original options' ranking has been adjusted by the researcher together with BIM manager by altering the priorities of the criteria within BeF. Its final decision is shown in Table 6-11: under column 'Adjustment trend'. The adjustment decision has been shown. Please note, two decimal places have remained.

Dimensions & factors to be adjusted	Influence factor		
	Commercial value	Sustainability	Customer's satisfaction
Project management	**0.02**	**-0.01**	**-0.01**
Technical & tools requirement	-0.01	0	0.01
BIM deployment	0	0	0
Legal & contractual	-0.03	0.03	0
Log management	-0.02	0.02	0
Project performance evaluation	0.02	-0.01	0
Customer & quality assurance	0	-0.01	0.01
Resource allocation	0.01	0	0
Application management	**0.03**	**-0.03**	**0**
Energy & sustainability	-0.02	0.02	0
Quantity take-off	0	0	0

Organisation management	**-0.01**	**0.01**	**0**
BIM performance evaluation	-0.04	0.02	0.02
Consistent vision	-0.08	0.04	0.04
staffing skill, plan & training	0.04	-0.02	-0.02
Business reengineering	0.06	-0.02	-0.03
Stakeholder involvement	**-0.03**	**0.01**	**0.02**
Government & public involvement	-0.02	0.02	0
Software vendor	0.01	-0.01	0
Manufacture	0.01	-0.01	0

Table 6-11 Sensitivity analysis of factor & dimension change trend

By shifting the priority of the factors in Table 6-11 above, it will affect all other criteria. The new set of priority are shown in Table 6-12 below:

Hierarchy Level	Goal/Dimension/Criteria/Sub-criteria	Original weight (%)	New global weight (%)
1	Goal: Future objective orientation of modern AEC organisation, a case study of ASZ	100	100
2	**Project management**	26.7	17.8
3	Project execution	9.9	6.6
4	BIM deployment	2.4	0.7
4	Roles & Responsibilities	0.9	0.3
4	Collaboration Environment	1.4	0.4
4	Process & Plan of work	1.6	0.5
4	Change order	1.3	0.4
4	Technical & tools requirement	1.1	2
4	Innovation	1.2	0.4
3	Project maintenance/administration	16.8	11.2
4	Legal & contractual	2.3	3.7
4	Resource allocation	2.2	0.4
4	Log management	1.2	5.3
4	Customer & quality assurance	3.1	0.5
4	Data management	1.6	0.3
4	Project performance evaluation	3.1	0.5
4	Risk control	3.3	0.5
2	**Application management**	8.4	24
3	3D visualization, coordination & clash detection	0.7	0.4
3	Quantity take-off	1.5	0.9
3	Energy & sustainability	0.5	3.4
3	4D schedule management	2	1.2

3	5D budget control	2.5	1.5
3	FM	0.7	0.5
3	Safety & environment	0.5	0.3
2	**Organisational dimension**	50.6	33.7
3	Consistent vision	3.4	17.8
3	BIM performance evaluation	25.3	9.5
3	Business process reengineering	12.3	2.7
3	Staffing skill, plan & training	6.3	2.4
3	Internal R&D	3.4	1.3
2	**Stakeholder involvement**	14.2	24.5
3	Owner/client	5.1	2.3
3	Designer	2	0.9
3	Contractor	1.2	0.5
3	Manufacturer	1	0.8
3	Software vendor	0.7	0.3
3	Institution	0.7	0.3
3	Government & public	3.4	19.6

Table 6-12 Global priority before and after Sensitivity analysis

A new option ranking was also obtained as shown in Figure 6-6 overleaf, where the percentage of Commercial value was reduced to 48.11%, customer satisfaction only improved by about 2%, and the percentage of sustainability was improved by about 11%. The adjustment did not provide a very obvious difference compared to the original trend. Since at this initial transformation stage, the strategy and action taken should be more conservative, to avoid any potential profit lose and risks. As such, a better decision and strategy can be made by BIM manager (Triantaphyllou, 1997).

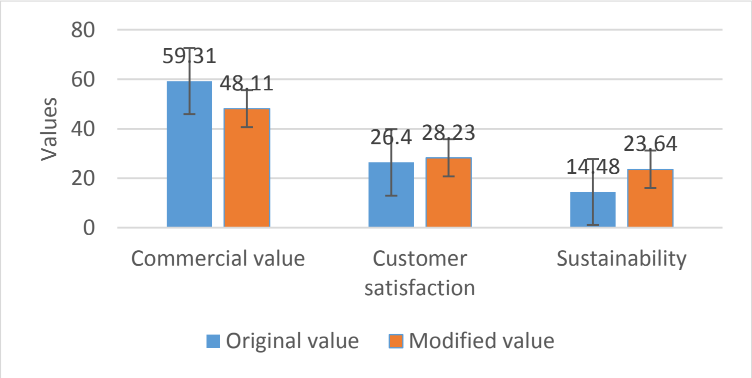

Figure 6-6 Comparison of alternatives rankings before and after factor priorities shifting

6.4 Summary

The criteria concluded from Delphi method was renamed, merged, removed and re-categorised to keep only managerial criteria to form a hierarchy AHP model that was approved by ASZ. In order to obtain the priority of each criteria, as well as current ASZ's focus schemes, Analytical Hierarchy Process (AHP) method was adopted. The global and local weights of each criteria was calculated by using the commercial application tools: Make It Rational (MIR). The result shows ASZ has a focus on the BIM adoption from the organisation level.

Based on the weightage system, a BIM evaluation Framework (BeF) has been developed. Firstly, a link among all managerial criteria and technological criteria was established. Secondly, each criteria was divided into various levels, from non-BIM capability to collaborative BIM capability. Thus, the third research questions has been addressed: '*How to develop a multi-criteria decision making tool to assist in strategic BIM implementation and assessment for an organisation?*'

In order to validate the efficiency, effectiveness and user satisfaction (e.g. BIM manager) of the developed evaluation framework, BeF was used to assess five completed projects from horizontal and vertical angles. The validation shows a good correlation - if an AEC project received a higher credit by using BeF, it means a better project performance in terms of profit, quality, efficiency and client satisfaction. The results also revealed that the level of BIM usage could also be related to the client's requirement, management paradigm and contract & legal aspects.

In order to validate the accuracy of the proposed BeF, other existing BIM assessment frameworks (provided by: I-CMM, BMP, OBIM and ABMF) have been selected to conduct the validation first. The results obtained by each individual assessment method all have a similar trend compared to the result obtained by BeF. Thus, the fifth research questions has been addressed: '*How to, by implementing BIM, to achieve the most preferable strategic goals (e.g. sustainability, customer satisfaction and commercial value) for an organisation through altering their current criteria priorities?*'

There are three focus schemes proposed by ASZ management team. The current ranking score obtained by MIR shows ASZ's attitude is focusing on the creation of commercial value (59.31%). In order to meet the need of company's new objective on sustainability and customer's satisfaction, sensitivity analysis was adopted. The influence of each criteria towards each focus scheme has been identified by MIR, the weight of criteria with a positive influence to *sustainability* will be improved, and criteria with a positive influence to *commercial value* will be reduced. After shifting the criteria's priority, the new rankings for ASZ's focus schemes are: commercial value (48.11%), sustainability (23.64%) and customer's satisfaction (28.23%).

Chapter 7. Discussion

The theoretical study

The basic purpose of literature review is to help the researcher to gain a general understanding of current research in the BIM implementation and assessment domain. A broad literature review was conducted, focusing on BIM standards, guidelines, protocols and execution plans for BIM practical adoption; existing BIM implementation and BIM assessment frameworks. The literature is not limited by nations, types of buildings, disciplines or any other constraints, hence it provides a generic context.

The outcome of literature review includes: understanding recent BIM implementation works, their implementation theories and methods; summarising key implementation areas of BIM; identify the defects and gaps existed in current BIM assessment criteria selection, criteria weightage calculation, assessment coverage/expandability, validation, impact of criteria towards organisation's goal etc. Based on this, 11 criteria have been proposed, which have been followed to develop a AHP based BIM assessment framework.

By the end of literature review session, a BIM implementation Framework (BiF) with 5 dimension and 69 criteria has been proposed to cover all aspects of BIM implementation in design stage. This has been further divided into five dimensions: project management, data management, organisational management, application management and stakeholder's involvement.

The case study

In order to further refine the preliminary BiF and also test its usability, firstly a pilot BIM project has been carried out within the research group. The author took the role of BIM manager, while other researchers with relevant BIM knowledge represented other disciplines. (e.g. structural design). The proposed BiF has been tried with a focus on the interaction among disciplines.

Based on the lessons learned from the pilot project, the revised BiF has been further adopted in a real project to collect Empirical data to test the usability, accuracy and reliability). Hence a local design organisation in China (namely, SAIXA) with no BIM background has been selected.

In order to fully understand the need of SAIXA, observation work was conducted and filed note has been used to record the current practice, such as software use, collaboration approach, data management method and process. Moreover, the defects of traditional approach have been summarised as well. Based on the observation, the current user's readiness and acceptance level of BIM can be identified.

A tailored BIM implementation guideline was developed for SAIXA. Firstly, BIM was considered from the organisational level to follow a top-down approach. A new BIM department was established including all design disciplines. They followed BIM based business process, proposed new services to clients as well as new KPIs to evaluate their performance.

As a result, the proposed BiF has been verified in practical adoption to avoid incorrect information being conveyed through the model. In order to shed light on current practice, levels of preparation and acceptance of BIM in China's AEC industry, questionnaires as a quantitative method were adopted after the case study.

The questionnaire

In this research, questionnaire was firstly distributed to UK's AEC industry (in early 2012) to understand the BIM adoption barriers in UK; and later the revised questionnaire was distributed in China. In order to compare to other countries E.g. US, UK provides a more incremental progress development process, which is more suitable to China's BIM development.

In order to reflect the most average status of current AEC industry and BIM application in both countries, questionnaires have been distributed in different regions: both England and Wales from the UK and three provinces from China mainland.

Questionnaire result shows BIM has been most used during the design stage, while UK received a higher usage rate compared to China. The communication approach, data storage and exchange method, as well as format of model in China are all traditional method based, which lead to low productivity and efficiency. The highest ranked barriers of BIM adoption in the UK (as summarised in 2012) were: people's willingness to change, cost issues and software and training availability. For China

Mainland, according to data collected in 2013-2014, it is more urgent to improve people's awareness in BIM.

The questionnaire result proved the proposed BiF has included all key implementation area and barrier for future improvement. After this research step, the first research question has been fully addressed: '*What are those dimensions and factors for BIM implementation and evaluation?*'

Nevertheless, the use of BIM could be different based on different policies, cultures, business structures and legislation etc. in different country (Howard and Björk, 2008, Miettinen and Paavola, 2014). Different disciplines also have different backgrounds, interests, risks competencies, maturity levels etc. (Succar, 2009a, Khosrowshahi and Arayici, 2012). Therefore, the concluded BiF should be validated within a specific context; and considering all stakeholders are sharing the same project target and constraint, their feedback and consensus on the proposed BiF should be considered. Thus, the Delphi method was adopted in the next research step.

The Delphi findings

The Delphi method was adopted to address the second research question: '*What are the most applicable criteria for BIM implementation in the design stage in a specific context, e.g. China*'.

Questionnaire design: the questionnaire is based on the concluded BiF in previous research step, the importance of its criteria is judged based on 1-5 Likert scale by participants. In order to ensure the response rate and quality of the data, all criteria's definition need to be concise and clear. Most importantly, instruction will be given at the beginning of the questionnaire to guide the participants.

Selection of context, organisation and participant: this Delphi study is for China context. The reasons are: China is a developing country and now in its initial stage for BIM implementation. They have the intention to improve and mandate the use of BIM broadly in china, hence there is an urgent need. Most importantly, this study is fully supported by the local industry consortium in China, for example: provide manpower for questionnaires and workshop. The findings could also benefit BIM users in other regions as the foundation of the developed BIM implementation framework is generic and was concluded from broad comprehensive literature review in the first place. In term of organisation selection, this study has selected a design company, a consultant company and a research based design institute to fully consider different types of organisations. Moreover, these organisations are located in different location in China, some of them also has branch and projects in other cities. The participants of Delphi study have been selected from the BIM department/team from all organisations.

Questionnaire distribution and collection: In this research, a personal visit was conducted before the first Delphi round, to give a presentation to all participants to make sure the research intention will be understood. While the anonymity still remained among all respondents to avoid pressure from others. For the following rounds, PDF based digital questionnaire was sent to all participants through email individually.

Questionnaire analysis: In this research step, five factors have been removed after Delphi round 1 based on participants' comment as well as median and mean value calculation (duplication with other criteria), one factor was proposed which resulted in sixty five criteria in total. The consensus of all criteria have meet a standard level, hence Delphi study stopped by the end of round 3. In order to enhance the validity of Delphi, follow up interviews have been conducted with the manager or director of all organisations, and workshops have been organisation with their BIM teams.

The AHP findings

Participant selection: the criteria within the BIM implementation Framework (BiF) in previous step were refined within China context, hence a design organisation has been selected from China to apply the AHP method: it should have participated in the previous Delphi stage to maintain a consistent data environment; it should be able to provide a certain level of BIM knowledge and experience in managing BIM based projects. Therefore, Arup ShenZhen office (ASZ) was selected.

Hierarchy model design: Based on the BiF obtained in previous step, a revised framework from managerial perspective was developed, including five levels: level one contains the AHP target, level two contains main dimensions, and level three and four contain criteria and sub-criteria, with ASZ's three focus schemes (commercial value, sustainability and customer's satisfaction) at level five.

Questionnaire distribution & analysis: The analysis of AHP method is based on pairwise comparison among all criteria under the same parent. Each of this comparison has derived a matrix, the eigenvector of this matrix represents the local value of each criteria. The global weight of each criteria can be calculated by multiply each criteria's local criteria with the local criteria of its parent. In order to improve the validity and consistency of the result, criteria under each parent should be less than seven. In a similar fashion, the ranking score of all three focus schemes have been obtained as well. The data collection process was based on questionnaire approach, the author send all questionnaire to each participant through email.

AHP study result: in order to facilitate the calculation process, a commercial application: Make It Rational (MIR) was adopted. The result shows, '*organisational management*' dimension ranked highest, followed by '*project management*', '*stakeholder involvement*' and '*application management*'. In term of criteria, the top four ranked criteria is '*BIM performance evaluation*', followed by '*Business process reengineering*', '*staffing skill, plan & training*', and '*client*' involvement. This reflects ASZ has already realise the important of BIM development in organisational level, as well as the importance role of client and government agencies (follow *client*).

BIM evaluation Framework development: based on the calculated global priorities, a BIM evaluation Framework (BeF) was developed. The weight of each criteria has then been equally allocated into various levels to present different capability of BIM (from non-BIM level to collaborative BIM level) for each criterion. Radar chart and bar chart have been adopted for comparison: targeted BIM usage level vs actual BIM usage level; or among projects: BIM usage level of project A vs BIM usage level of project B etc.

System validation: The validation includes three parts: the proposed BeF itself, the satisfactory of nD BIM model (based on 1-10 Likert scale) and project performance assessment. The researcher argues both BIM maturity level and performance can be improved with accumulated knowledge and experience gained. The selected test projects showed a good correlation between the BIM usage level and the project performance. The result also revealed the level of BIM usage is not really relevant to the project scale, project location or participants, but could be slightly influenced by client's requirement, management paradigm and contract & legal aspect.

In order to validate the accuracy of the proposed BeF, existing BIM assessment methods has been conducted as well to evaluate all projects (A-E). The result obtained from individual project, as well as their average value all demonstrate a similar trend compared to the result obtained from the BeF.

Sensitivity analysis: The ranking score shows the current focus is on '*commercial value*' (59.31%). Which means the current factor priority could bring more commercial profit. However, regarding the need of the current AEC industry and ASZ' strategy, more resource should be focus on 'sustainability' (14.48%) as well as 'customer's satisfaction' (26.4%). Therefore, sensitivity analysis was adopted to improve ASZ's attitude on 'sustainability' and 'customer's satisfaction' by shifting the original priority of all criteria, where 'sustainability' has been improved by almost 10% and up to 23.64%, and customer's satisfaction has only increase by nearly 4% and to 28.23%.

Generalisation of the research findings

Based on the experience and result gained from the AHP study, ASZ can further improve its BIM implementation towards higher long term objective: (1) ASZ could propose new focus schemes to meet specific client's need therefore to expand their BIM capability; (2) In order to further improve the efficiency of the AHP result, ASZ could develop an upgraded version of analytical hierarchy model based on the highest prioritised criteria after sensitivity analysis for new focus scheme: sustainability; (3) ASZ could use the same criteria to conduct another AHP study with a different 'AHP target/goal' and different 'focus schemes';

Other design organisations in China can replicate the AHP study process for their strategic use directly based on the Delphi result, since the final qualified criteria have been achieved by Delphi consultation. The hierarchy framework, AHP target/goal, focus schemes used by ASZ can be adapted for new uses.

The priority of BIM implementation criteria also reveal what is the most needed in China now, this could assist associated institution or research organisation to develop associated standards or guidelines to improve BIM capability in China.

The BIM implementation Framework (BiF) as presented by the end of research step three (questionnaire) is generic, since it was concluded from worldwide existing BIM literature (guidelines etc.). As such, it is suitable and applicable to design organisation in many countries. The Delphi and AHP process can also be conducted with different context.

The author believes to compare the Delphi results among different countries could reveal how political environment and cultures in different countries can influence the adoption of BIM. The comparison of AHP result between different organisations in the same country could reveal how the weighing system could be affected by organisation in different regions, with influence from their own objectives as well as decision maker’s preference.

From another perspective, it could also enable researchers to compare the capability of BIM in different organisation in the world, therefore a benchmarking method can be further developed. . However, a few issues have to be resolved in advance, e.g. the selection of criteria needs to meet all organisation’s requirement. The developed BiF and BeF in this research have all considered the involvement of the ‘*government & public*’, since it has a significant impact on the BIM development status on a country level (Kassem et al., 2013). Hence based on the proposed framework, benchmarking (Sebastian and van Berlo, 2010, McGraw-Hill Construction, 2009) can be developed for comparison between organisations or even countries (Succar and Kassem, 2015). The suggestion is to select BIM users worldwide to participate on both the Delphi and AHP studies.

Limitation

In the second research step: case study, due to the project progress and client’s requirement, only major criteria within BiF have been validated. The selected case study could provide an in-depth analysis to provide enough information for the research purpose, but if there are more projects with different types to be chosen, it could better demonstrate the efficiency of the developed framework.

In the third research step: questionnaire survey, the data collected only demonstrated the status of BIM in China around 2013 to 2014, which will be outdated by today (2015). Respondents should also come from all provinces with an equally number of participants, however this is challenged with the consideration of limited time and budget of this research, therefore three representative provinces have been considered.

The participants in Delphi study is mainly from ShenZhen city, even though they have many projects in other cities as well as partners from other provinces, the regional issue as well as the local government's strategy could lead to an uneven BIM levels in different places. In order to balance the result, participants from selected organisations' branch in other cities (e.g. Beijing) have also been included, but the number of participants is still small.

In the AHP study step, the AHP study was conducted in Arup ShenZhen office (ASZ). The result in ASZ could not represent other offices in different region or nations. The weight obtained from AHP could be used as a general guide or perception in ASZ.

The final research outcome: the BIM implementation Framework (BiF) is most suitable for China's context, and the BIM evaluation Framework (BeF) is ideally most suitable to ASZ, as both are context specific. However, the developed preliminary BiF is generic; and the developed six-step research methodological framework is also generic and can be used for generic BIM evaluation and strategic planning. The Delphi and AHP methods have been used in many other domains for decision making purpose, this research has added case study and questionnaire to investigate the usability of the proposed framework in real context. The proposed methodological framework can be adopted by other countries for the similar purpose.

Chapter 8. Conclusion

Answering the research questions

This research aims to develop a BIM implementation and evaluation Framework (BeF) to strategically implement BIM for design stage. Therefore, a mixed qualitative and quantitative approach was adopted.

The first research question is: '*What are those dimensions and factors for BIM implementation and evaluation?*' The strategy chosen to answer the first research question was a theoretical study, involving the existing BIM standards, guidelines, execution plans and existing assessment frameworks etc. This lead to a recognition of the need of such an assessment method, as well as the defects of existing methods. A BIM implementation Framework (BiF) was developed with five dimensions: project management, data management, application management, organisational management and stakeholder involvement. The proposed BiF is believed to be generic and applicable to all cases, regardless its types of project, cultures of stakeholders or even political environment.

The proposed BiF is based on theoretical knowledge, therefore it is important to test its reliability and usability in reality. Therefore the second research step: case study was adopted. A pilot case study within the research group were conducted first, where the most fundamental criteria for BIM implementation have been tested. The use of BIM could be influenced by variables like policies, cultures, business structures and legislation etc. Hence the selection of case study, as well as some of the research steps (e.g. Delphi & AHP) need to target a specific country, because the use of BIM can be influenced by many factors, such as policies, cultures, business structures and legislation. In this research, China has been selected because it has one of the largest construction market. Moreover, the government of China has recently released the strategy to use BIM in 90% of its project by 2020. As a new BIM user organisation (namely: SAIXA), the adoption of BiF in SAIXA could better demonstrate the efficacy of the proposed framework: BIM has been firstly adopted from the organisational level, followed by the data management policy within and cross organisations. Later on a real project was chosen to apply BIM from the project management and application management. The result proved the proposed BiF has covered all the issues during BIM practical implementation.

The limitation of the case study was the limited number of participants. Therefore, it was necessary to understand the judgement on the comprehensiveness of BiF from an industry level. Since there is no possible method to assess the proposed BiF in a national level in a same way as the case study, a questionnaire survey was adopted to collect data from industry practitioners who could represent the entire AEC industry of China. The first questionnaire was conducted in the UK, to identify people's current practice, BIM status, adoption barriers and expectation for future development of BIM. Based on this, a second questionnaire with modification specific for China's context has been distributed to both China Mainland and Taiwan (Republic of China: ROC) for comparison. The result showed China Mainland has a much lower level of BIM usage in the AEC projects than UK and ROC. The questionnaire result also revealed the proposed BiF has included: weak point of current BIM practice, adoption barriers and future development need of BIM.

The second research question: '*What are the most applicable criteria for BIM implementation in the design stage in a specific context, e.g. China*' was addressed by conducting a consensus based method: Delphi study in China. By adopting a three rounds questionnaire, the selected experienced BIM user's opinion towards the proposed BiF has been precisely considered. Five criteria have been removed and one criterion has been newly added. The refined BiF is believed most suitable to China's context.

As a defects of Delphi method, it only filters the most important criteria. However, in order to evaluate the usage of BIM in practical adoption, especially to implement BIM in a more strategically way, several things were required. Firstly, a weighting system was needed. Secondly, how BIM could influence the organisation's objectives needed to be identified.

This therefore led to the third research question, '*How to develop a multi-criteria decision making tool to assist in strategic BIM implementation and assessment for an organisation?*' The Analytical Hierarchy Process (AHP) method has been employed. Ten experienced BIM users (BIM manager and BIM senior engineer) have been selected from Arup ShenZhen office (ASZ) to participate in the AHP session. A hierarchy model was established by ASZ management team based on the proposed BiF with the purpose to evaluate BIM and strategic planning. A commercial professional application: Make It Rational (MIR) has been adopted to calculate the priorities of all criteria. Based on the weighting system, a BIM evaluation Framework (BeF) was developed with the following applications: to assist project manager or BIM manager to develop BIM strategic planning in practical adoption based on the priority of each criterion; to assess the current BIM usage level, identify the weakness, strength and what is missing from the current practice; to be adopted by client for prequalification selection for the optimised designer during the bidding stage.

The fourth research question was proposed to validate the proposed BeF: '*How to validate whether the proposed evaluation framework is practical to use, as well as its efficiency, effectiveness and user satisfaction*', the validation process has been designed. Five completed projects have been selected and proved a higher result assessed by the BeF, a higher project performance can be achieved. In addition, existing assessment methods have been used as well, their individual assessment result as well as their average value among them all present a similar trend compared to the result obtained by the proposed BeF.

The ranking order of three focus schemes proposed by ASZ was obtained: it shows the current attitude of ASZ is on 'commercial value' (59.31%). In order to have more focus on the 'sustainability' as well as 'customer's satisfaction', sensitivity analysis was adopted. By modifying the priorities of criteria within the hierarchy model, people's attitude on different focus scheme can be shifted as well. Therefore to address the research question fifth: '*How to, by implementing BIM, to achieve the most preferable strategic goals (e.g. sustainability, customer satisfaction and commercial value) for an organisation through altering their current criteria priorities?*'

Therefore this six steps of research has well answered the research hypothesis: '*A BIM evaluation framework including key dimensions and criteria that are relevant to BIM practical deployment during the design stage can help to improve the performance and strategic development for an organisation'*.

Research contribution

The first contribution of this research is to the BIM implementation strategies, in the AEC industry context: a generic BIM implementation Framework (BiF) which aims to implement BIM from five dimensions: project, data, application and organisational management as well as stakeholder involvement was proposed. The BiF will not be constrained by culture, policy, political environment, discipline and project types etc.

Secondly, this research has contribution towards the AEC industry of China. The BiF was refined by Delphi in China, which can be used by other organisations in China. Moreover, new focus scheme can be added to the original AHP framework proposed by ASZ. In addition, they Delphi and AHP approach can be replicated for any other decision making problem.

Thirdly, the proposed BeF has contributed to the BIM adoption within ASZ: to facilitate ASZ to improve their level of BIM usage by revealing the weak point and missing area, to apply the highest prioritised criteria to meet a higher BIM usage level if the resource is limited.

Lastly, the developed BeF has also contributed to the assessment of BIM usage level, since less attention has been paid to the involvement of stakeholders during the design stage, instead, existing assessments have a focus mainly on the data process. Even though some existing method have include BIM evaluation from the organisational level, while the assessment criteria still require rigorous selection and validation based on specific context, for example countries. The validation stage has proved the internal variables (e.g. project types, client requirement, project management approach and budget limit etc.) could influence the BIM usage level in a microscale, while the external variables' impact (e.g. culture and political environment etc.) still require further test.

Most importantly, the weighting system should be calculated in a reasonably way, instead of using average value or assumption. In addition, organisation's focus schemes should be considered therefore to provide a more appropriate strategic planning for BIM development.

Recommendation for future work

The main objective of this research is to prioritise all criteria that relevant to BIM implementation during the design stage. Therefore it might be interest to develop an updated version of AHP model, where the criteria with a lower weight in the current AHP model will be eliminated (Shapira and Simcha, 2009). In order to achieve this, rules have be established of which criteria to be removed and how the weight of eliminated criteria to be assigned to remained criteria.

As BIM is still at its early stage in China, therefore the proposed BeF from an abstract level will be sufficient to deploy BIM strategically. However, with BIM deployment continue in ASZ, more details need to be analysed. Each criteria within the current AHP model can be further developed into a separate AHP model. For example, for criteria: ‘collaboration’, a new AHP model with the goal: ‘how to identify the most important criteria for collaboration under BIM environment’ can be identified, this could facilitate developing the best collaboration strategy, or assess the excellence level of current strategy, which could also be used to select the best collaboration out of several alternatives.

Sensitivity analysis has been employed to alter the weight of original AHP result, the increase or decrease in term of each specific criterion’s weight should be discussed with the BIM manager in ASZ to better understand how they exactly influence different focus scheme, and how to carry out these change in reality. In addition, the sensitivity analysis are based on human’s judgement as well as numerical information calculated in theory environment only, the actual result in practice still need to be proved by numerical evidence: if people’s attitude has more focus on ‘sustainability’ than before, and how much more.

The implementation framework (BiF) as well as assessment framework (BeF) required to be reviewed by BIM manager from time to time with a minimum one year interval regarding to the criteria that been used for assessment and if there is any changes in focus scheme. And the weighting system as well. In order to provide a more precise weighting system, the weighting calculation stage (pairwise comparison) should be duplicated and conducted for different types of project (e.g. R&D, commercial and residential etc.).

As mentioned the Delphi refined criteria for BIM implementation are suitable to China context, therefore is will be interest to applied the Delphi refined BiF into a different case: firstly, ASZ is an international based design organisation, its BIM usage level could be higher compared to local organisation, because ASZ can be influenced by its other branches in a more developed region (e.g. London). Therefore to replicate the AHP process in a local design organisation (who has a similar level of BIM capability compared to ASZ) could reveal the difference in prioritising criteria in different types of organisations. Moreover, regarding to the huge area of China, by conducting AHP in different organisations located in different regions (e.g. Beijing, Shanghai and Shenzhen etc.), it could reveal how the priority can be affected by regional difference.

From a country level, the concluded BiF after research step three can be applied as a basis in any other country to repeat Delphi – AHP study process, to compare the Delphi refined model as well as the prioritised criteria in another country with the result of China, this could contribute to the BIM development in the world's AEC industry.

Lastly, the researcher argues the proposed BiF and BeF have considered the involvement of government agencies and institution (academic), who will have a large impact on the country's BIM capability. Therefore the framework developed in this research has the capability to be further developed into a benchmarking method for the comparison of BIM between different countries. From another perspective, the researcher also believe the comparison between different organisation in different countries could also contribute to the world's BIM development, users from different countries could learn from each other for improvement. However, this will require a unified assessment criteria as well as weighting system (Shapira and Simcha, 2009). The researcher proposes by selecting participants from both countries for Delphi and AHP study could solve the problem from a shallow level, but further study need to be investigated.

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Appendix A BIM Guidelines, standards, etc. comparison & briefing

Please refer to CD.

Appendix B Review of existing BIM implementation frameworks

Please refer to CD.

Appendix C - UK questionnaire

Please see CD for the full version

Perception of existing BIM solutions/practices in the UK construction

Introduction

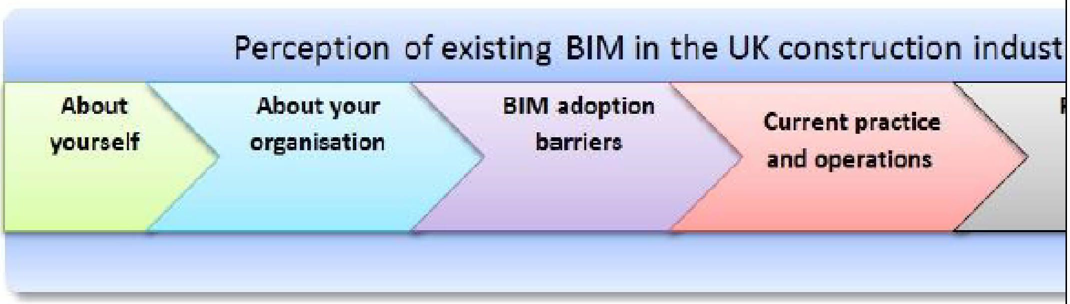
Dear Participant,

As part of BRE Trust research into Building Information Modelling (BIM) we would like to initiate a survey to establish industry's readiness to adopt BIM, as an information delivery mechanism for construction projects.

To date, there has been a strong agreement that construction projects are fragmented and highly regulated, making them challenging to handle. Throughout the lifecycle of a project, data with varying complexities and shapes are generated, which make them difficult to manage and govern in an efficient way. There exists an industry consensus that Building information Modelling (BIM) offers an effective means to deal with the complexity of generated data. Therefore, the community recognizes that there is a lack of a governance approach for governing BIM models throughout the lifecycle stages.

This survey (as illustrated in fig.1) aims to identify the BIM adoption barriers, current practices on typical construction project, and requirements for governance aspects.

Figure 1 survey structure



Participation in this questionnaire is strictly voluntary but strongly advised. We understand that you may not be able to answer all the questions asked here; if you are unsure or do not know the answer or would prefer not to answer, please leave the relevant section blank.

Data collected through this survey will be solely used for purposes described here and will be treated as anonymous and confidential.

Thank you for taking time to complete this survey. Your response will assist us in compiling evidence and based on this we could develop a generic BIM governance model.

For more information, please contact: pbimsurvey@gmail.com

Appendix D - China questionnaire

Please refer to CD for full version and translation version.

中国建筑行业的现状以及BIM的认知

简介

此调查问卷为卡迪夫大学 (Cardiff University) 计算机信息建模技术(Building Information Modelling) 研究团队研究计算机信息建模技术的治理模型而设计。此调查问卷旨在收集以及了解中国目前的建筑行业市场的情况以及所面临的问题，同时侧重于对计算机信息建模技术 (Building Information Modelling - BIM) 目前在建筑市场的影响力以及使用状况，部署方面的困难等问题的收集， 以便后期的研究与开发。

此调查问卷分为四部分：

第一部分：您的个人信息；

第二部分：您所在的机构；

第三部分：目前建筑业的现状；

第四部分：BIM的部署与问题；

参与者并不需要回复所有的问题， 您只需回答与您相关的问题即可。

调查问卷所收集的所有信息将仅用于本研究的使用，所有的个人信息以及回答信息将受到保护不会泄露与第三方。

十分感谢您的参与，您的宝贵意见将对作者的工作提供支持与动力。 若有任何问题，请与该课题的负责人 陈克宇 联系：

地址：英国 卡迪夫大学 工程学院 CF24 3AA

邮件：chenk3@cardiff.ac.uk

手机：+44 7729 793379

Appendix E Delphi method

Please refer to CD for full version.

Appendix F Delphi study invitation letter

W/1.30 Cardiff BIM Team
Cardiff School of Engineering
Cardiff University
Queen's Buildings
The parade
Cardiff CF24 3AA
Wales, UK

Invitation for research participants

15/12/2013

Dear respondent,

As part of the Cardiff BIM Team's research into Building Information Modelling (BIM) we would like to initiate a study to establish industries' readiness and adoption BIM management in the Architecture, Engineering, Construction and Operation (AECO) industry as an information delivery mechanism for construction projects in China. The applied methodologies are Delphi and AHP.

The Delphi method is a decision making tool that looks at finding a consistent judgment on attributes, through three questionnaires, each questionnaire will be answered by the same people and will take approximately 20 minutes each.

The Analytical Hierarchy Process (AHP) is a structured technique for organising and analysing complex decisions, based on mathematics and psychology. It requires one questionnaire which will take approximately 20 minutes.

Data collected through this survey will be solely used for purposes described here and will be treated as anonymous and confidential. Your contribution to this research is very important to the success of this study.

Please, don‘t hesitate to contact me if you have any questions.

Sincerely yours,

K. Chen (BEng)

PhD. Researcher, Cardiff University, UK

E-mail: Chenk3@cardiff.ac.uk

Tel: +44 (0)29 2087 4070 (w/1.30)

Appendix G Delphi round one, two and three questionnaires

Please refer to CD for full version (Delphi round 1-3) and translation version for Delphi round one, two and three.

影响BIM成熟度（部署以及应）的因素

研究目的
此调查问卷为卡迪夫大学 (Cardiff University – CU) 计算机信息建模技术(Building Information Modelling – BIM) 研究团队针对评估BIM在建筑项目中的应用成熟度而设计。

Delphi专家访谈法说明
此阶段的研究需要针对在实际操作中，对影响BIM成熟度的因素进行筛选并对其重要性达成共识，根据Delphi专家访谈法，需要进行三轮调查问卷工作：
第一轮：（即此轮）参与人员需要针对各因素在BIM成熟度的贡献值以及重要性进行评估，并提供对所列因素的看法，例如：建议删除个别不重要因素，或建议新增研究人员没有考虑到的因素等等。
第二轮：通过第一轮的筛选，因素在内容数量上会有小幅度改变（新增或删除个别因素），参与者此轮需要再次评估各因素的重要性，但不需要新增或删除因素；
第三轮：所列因素将会与第二轮相同，参与者在参考第二轮分析结果（即各因素各自的平均值）的基础上，再次进行评估，目的是避免在第二轮中有任何没有考虑到的情况导致结果受到影响。

此调查问卷说明以及结构
研究人员总结到，所有
此调查问卷分为八个部分：
第一部分：您的个人信息；
第二部分：您所在机构的信息；
第三部分：影响BIM成熟度的因素/因子，归纳为五个主要因子，参与人员首先针这五个主要因子进行评估；
第四至第八部分：参与人员针对每一个主要因子的子因子，次级子因子等进行详细评估，

例如：
1.1 代表第一个主要因子中的第一个子因子；
1.1.1 代表第一个主要因子中第一个子因子的次级因子；
1.1.1.1 则代表上述次级因子的再次级因子

评分标准如下：
评分 重要性说明
1 不重要
2 不太重要
3 适度重要
4 重要
5 很重要

保密守则
调查问卷所收集的所有信息将仅用于本研究的使用，所有的个人信息以及回答信息将受到保护不会泄露与第三方。
十分感谢您的参与，您的宝贵意见将对作者的工作提供支持与动力。 若有任何问题，请与该课题的负责人 陈克宇 联系：
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Appendix H AHP method

Please refer to CD for full version.

Appendix I Example of priority calculation in AHP pairwise comparison

Please refer to CD for full version.

Appendix J AHP questionnaire to ASZ

Please refer to CD for full version and translation version.

评估影响 BIM 的相关因素的重要性以及公司未来发展的方向

问卷目的

此调查问卷旨在：

1. 评估与 BIM 有关因素对本土 BIM 发展的重要性/影响力；
2. 评估在 BIM 环境下公司未来不同战略导向的影响力。

问卷请参考附件：“BIM 管理分层模型”进行答卷

问卷简介

此问卷分为三个部分：

1. 对主要 BIM 相关因素的比较
2. 对次一级 BIM 相关因素的比较
3. 对未来不同战略导向的比较

参与人员需要对 BIM 相关的因素以及战略导向/发展方向进行两两相比，以便得到其重要性。所需比较的对象列在表格的左右两端（示例请参阅表格 2-3），请根据对比重要度进行选择。重要度的标示符解释如下图（表格 1）所示：

表格 1 重要性指标说明

重要度强度	语言表达	解释
1	同样重要	作对比的两者同样重要
3	适度重要	评估人员认为其中一项适当重要于另一因素
5	强劲的重要	评估人员认为其中一项因素相当重要于另一因素
7	很强的重要	其中一项因素很重要于另一因素
9	极端的重要	其中一项因素远远重要与另一因素
2,4,6,8	介于以上评判标准之间的中间值以表达各自的重要性	

示例

如果您认为“硬件的提供”**同样重要**与“技能需求”，那么请您对中间的 1 进行*涂色或其他方式的标记*：

表格 2 示例 1

硬件	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	技能

Appendix K Sensitivity Analysis

Please refer to CD for full version.

Appendix L BIM implementation Framework

Please refer to CD for full version

Appendix M Follow-up Interview of Delphi

Please refer to CD for full version

Appendix N BIM evaluation Framework (BeF)

Please refer to CD for full version in Excel document, as well as project A-E evaluation result.