A Gamificative-based Information Coordination Framework for Building Design Practice to Improve Business Operation Performance

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Abstract

Poor information coordination in building design practises, including inadequate comprehension, insufficient communication and inefficient collaboration, results in low productivity. The business performance of building design companies is highly dependent on production delivery qualities and efficiencies. Lack of data accessibility, including poor data coordination, prevents the client and other project stakeholders from having a clear understanding of certain details of the building. Consequently, the project faces a range of challenges such as increased uncertainties (e.g., functional and spatial disorders), leading to repetitive modification and delay in the delivery of design drawings. Despite the existence of the Building Information Modelling (BIM) paradigm and its relevant technologies, it is still unclear how building design practices can be improved to ensure better business operations performance. Current practices in building design companies are still largely based on traditional schemes, with little impact from BIM. Hence, it is vital that building design catches up with the rest of society, in terms of digital transformation.

Therefore, this research aims to propose a conceptual framework for guiding building design companies to improve their business operation. This framework incorporates the BIM paradigm from a business angle, aiming to help building design practices to improve their business operations and thus impact positively on client satisfaction. The research has three core objectives: to investigate issues in building design; to understand the features of LOD 350, ISO 19650, and Gamification; and to explore how information coordination can impact the business operation of building design companies.

On this basis, the researcher has used an interpretative-oriented paradigm, which uses the mixed-method approach to explore why and how a gamificative environment can impact building design business operation. The first stage uses primary data from semi-structured interviews and secondary data from literature reviews to explore the solutions from management, technologies, and standards, identified through the integration of ISO 19650, LOD 350, and Gamificative Technologies. The second stage uses the primary qualitative data from evaluations through intervention studies to test the proposed conceptual framework; research has identified that different gamificative technologies have the same impact on building design business operation. The third stage uses both qualitative and quantitative data from focus group discussions and a survey to measure the proposed conceptual framework in terms of feasibility and strength. Findings have shown that all features and factors within the gamificative environment have a significant impact on building design business operations.

Findings show that the business operation of building design companies is impacted by their productivity. With the features from Gamification, LOD 350, and ISO 19650, both stakeholders and design teams, in collaboration with the client, can have a better understanding of the building project through a realistic and interactive environment that incorporates spatial data coordination with design information. In addition, research shows that increased information coordination improves capabilities in decision-making, collaboration, communication, and management. Hence the quality and the schedule of the building design is being improved in such a way to increase design productivity based on clients' wishes through enhanced business operation performance.

The novelty of this research is that it has incorporated a Gamificative-based Environment with building design practises for connecting BIM models and design development by adopting immersive and interactive visualization technologies to increase the engagement between client and architect over a common data environment that advocates and thus improves design business operations. By adopting this approach, this research can help the building sector (in particular, architecture) to adopt this concept to develop their competitive advantage and manage to grow and sustain their businesses operation in a more intelligent, effective, and efficient way.

Keywords: Gamificative Environment, Interactive and Immersive Technologies, Information Coordination, Business Operation

Chapter 1: Research Introduction

1.1: Motivation

1.1.1 Consequences of Poor Information Coordination

Poor information coordination in AEC projects will cause many issues in society, the environment, and economics (Holzer, 2016). The global population has increased dramatically from 2.6 billion in 1950 to an expected 9.8 billion in 2050, according to data from the United Nations (UN). The AEC sector accounts for most of the gross domestic carbon dioxide emissions in many countries. For example, in China, according to data from the China Association of Building Energy Efficiency (2020), total carbon dioxide emissions from AEC industries are 4.93 billion tons, which account for 50% of total domestic emissions. The data also shows that emissions from material production accounts for 2.72 billion tons, which is 28.3% of gross domestic carbon dioxide emissions. This waste of materials in building construction will cause further greenhouse gas emissions, whilst poor performance in project management negatively impacts society and the environment due to inappropriate working methods such as lack of care, lack of skills and lack of knowledge (Rose, 2013). Therefore, transformation of the AEC sector is urgently required in order to improve the situation, since more resources need to be saved for supporting human living activities, and to minimize waste and reduce greenhouse gas emissions.

Moreover, many of the resources wasted during production in the AEC sector are caused by lack of sufficient information coordination, meaning that these resources are not being properly used (Farmer, 2016). Due to poor coordination of information, 15.2% of time is being wasted on rework, 16.2% on conflict resolution, and 14% on seeking data during project development (PlanGrid, 2018). The lack of information management causes over 14 hours per week to be wasted (PlanGrid, 2018). Additionally, Taylor (2000) has pointed out that bad coordination will increase risk during the development of the building project. Therefore, to avoid those problems, and from an economic aspect, information coordination is one of the most important aspects of AEC projects.

More specifically, the direct consequence of poor information coordination at the design stage is in spatial clashes during the construction stage, which reduces delivery quality and efficiency (Wolstenholme, 2009). According to many reports, uncoordinated 2D diagrams of low quality, with missing information, and which are difficult to build (Rounce, 1998), negatively impact building construction. Poor coordination causes ambiguous information, which subsequently impacts project construction, both spatially and geographically. Another aspect which causes poor coordination is lack of access to the same information during project development (Murray, 2008). Inconsistent information accessibility leads to misunderstanding of project information, which in turn leads to project delay, incorrect production, etc.

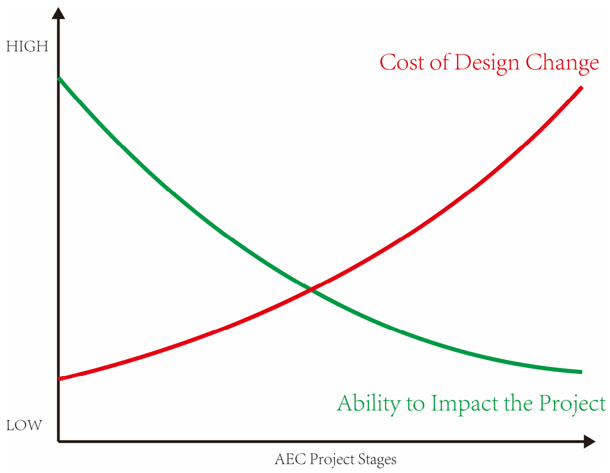


Figure 1.1 a: MacLeamy Curve (MacLeamy, 2004)

Since design is the most important stage of an AEC project, the delivery of design has a direct impact on construction and operation (Murray, 2008).

According to the findings, unshared information, delayed information, and missed information are common issues during building design development that cause project failure. MacLeamy (2004) has argued that the earlier the intervention, as regards coordination, the less cost will be affected during project development and likewise the project itself (Figure 1.1.a). Therefore, in this discipline, there is an urgent need for increased information coordination at the early stage of building design, in order to improve the quality of the design delivery, which can subsequently impact on all AEC industries, helping society, environment, and economics.

1.1.2 Current Situation in the Chinese Mainland Building Design Market

One of the major differences between the Chinese building design market and the western AEC market is that design companies in China comprise all design disciplines, including architecture, structure, and MEP for the final design documents delivery. In Chinese building design market, however, more aspects need to be considered during the design development process to ensure design documents meet required standards. In such a work environment, a high level of coordination, collaboration, and communication is required to ensure the entire building design can be completed on time to the satisfaction of all stakeholders. This is a challenge, but also a significant advantage for project development. The challenge is how to enable all disciplines to work effectively and efficiently, while the advantage is that the design manager can control the entire design process to ensure that all disciplines in design development are running in the desired manner. This research is focusing on the Chinese building design market to investigate how building design quality can be improved in Chinese building design companies based on the cooperation of all the design disciplines.

China has the biggest AEC market in the world; in 2016 the market was 7.1%, in 2017 10.5%, and in 2018 9.9%, according to the China AEC annual report (Z.

Zhang, 2019). The AEC sector makes a significant contribution to the country's GDP (6.87%) with millions of people relying on the sector to make a living (AEC sector weighted 7.17% of total national employment). Total investment on fixed assets in 2018 was 65 trillion CNY (7.36 trillion GBP), growing at a rate of 5.9% (Fu et al., 2019). However, the performance of AEC industries in China is relatively low compared to more developed countries; according to the China BIM annual report, profits of Chinese AEC industries amount to just 1.84%, compared with 4.68% for advanced foreign AEC companies (Fu et al., 2019). It is clear, therefore, that the Chinese AEC market needs to transform from labour-intensive mode to technology-intensive mode in order to increase competitivity (Zhang, 2019).

The digitalization of AEC industries is extremely low compared to other manufacturing sectors (Fu et al., 2019). According to the UK BIM annual report, 62% of people agree that AEC industries fall far behind other industries in terms of digitalization (NBS, 2019). In China, digitalization in AEC sectors in 2014 was only 0.03%, and in 2018 the size of the BIM market was only 10% of its estimated potential (Fu et al., 2019). According to statistics from the China BIM Union (2020), BIM education has increased markedly in recent years; many universities and enterprises provide training, which shows the potential capabilities of BIM to impact AEC industries. Technology innovation can help to solve issues and increase productivity (Hardin, 2009). With the development of Building Information Modelling (BIM), by 2019, 81.19% of AEC industries had adopted this strategy in their projects, and 14.98% of these companies had applied BIM to every project (Wang, 2019).

Beside implementing BIM in design businesses, an additional challenge is the associated costs related to technology investment, people training, etc. The deployment of required human resources and IT resources are major concerns for many AEC industries in terms of return on investment. Furthermore, despite

BIM implementation in building projects, 51.04% of AEC industries do not have a clear implementation strategy, while 31.22% of companies do not have any idea where to start (Fu et al., 2019). It is important to avoid mindless digitalization strategies in building project management (Glodon, 2020), as lack of clear guidance during technology adoption - especially endeavour into a new area - will have an effect on overall performance (Alreshidi et al., 2017). Incorrect BIM adoption will increase expenditure without substantial positive contribution (Jia et al., 2015). To avoid this kind of situation, efficient integration of people, process, and technologies by using standards, methods, and procedures (SMPs) is required to be adopted in BIM-driven projects for improving design management.

AEC-related design is one of the most important sectors in the Chinese AEC market, with the total income of the survey and design sector amounting to 5.2 trillion CNY (0.59 trillion GBP) in 2018, and the design sector amounting to 406 billion CNY (45.96 billion GBP), according to the China AEC annual report (Zhang, 2019). Building design companies are responsible for all technical and engineering design during project development, guiding all stakeholders in relevant building codes (MOHURD, 2005). However, multiple problems exist in building design companies during the design process which cause insufficiencies in design management, leading to poor business operation performance (Zhang, 2019). This lack of information management during building design development causes poor information coordination and hence inefficient design production and delivery. Therefore, the Chinese AEC market urgently needs to improve the way it manages project information for improving the country's overall economic growth.

1.1.3 Problems in Traditional Management

Poor performance in project information management during the design stage will cause multiple issues during the later stages (e.g., construction and facilities management). What is required is optimization of the operation of building design companies as regards allocation of resources. Building design companies in the Chinese AEC market are facing an excessive design workload due to rapid infrastructure development, and inefficiency in design management, which directly impacts business operation. Since the traditional method of managing building design information has proved detrimental, design companies need to change to avoid fragmented and inconsistent project information, and hence enhance design performance (Wang, 2019).

Building design is becoming increasing complex, requiring collaboration between multiple disciplines. The traditional design process and tools cannot satisfy increasingly complex design problems (Hu, 2012) and, due to the massive amount of produced design data, including both graphical and non-graphical information, experience-based traditional evaluation processes cannot meet requirements; many designers are still using subjective methods of judging design development, which leads to errors and failure of project delivery (Xiao, 2019). Inefficiencies in the design review and evaluation process lead to poor quality of the management process during design production, which can affect the company's business operation. Hence the urgent need for a more efficient way to process design evaluation and development in building design.

Currently, there are multiple problems in building design management, which negatively impact design companies' business operation. These problems include poor integration of design information during the building design process, inefficient communication during the project development process, and insufficient assessment during the evaluation process, all of which lead to issues such as delay in project delivery, exceeding of budget and loss of potential clients (Best, 2006). More importantly, poor design delivery quality will seriously affect later stages such as construction and maintenance (Imrie, 2011). Design delivery is the main product offered by building design companies and its income accounts for most of the total business revenue (Knotten et al., 2015). Therefore, solutions to improve design management for enhancing quality of building design are urgently required. Improved quality of building design development will increase the quality of design delivery, which will lead to improved business performance of building design companies.

To improve design management, better information management and coordination is required to help design businesses perform in a more effective and efficient manner. Coordination of the design process and development needs to be optimized by Standard, Methods, and Procedures (SMPs) according to the ISO 19650 regulation. The motivation of this PhD research is aimed at finding solutions from management theories and state-of-the-art AEC technologies regarding increased quality of information coordination in the building design process for improving design quality, which can subsequently enhance the business performance of building design companies. Based on the identified aspects and technical perspectives, this research has integrated the most appropriate technologies to fill the gaps in building design management, which has created a conceptual framework based on the findings for the reference of BIM-driven projects development in Chinese building design companies.

1.2 Preliminary Research

1.2.1 Issues and Problems in Information Coordination

This research has conducted a semi-structured interviews from experienced AEC professionals during preliminary stage to identify issues and problems in building design information coordination. The detailed methods are listed in Chapter 3, Section 3.5 (**pp. 202-207**). Through reviewing the data collected from the semi-structured interviews, it was found that many of the answers submitted are related to space, and the geometry of building components is mentioned often. Therefore, this research has assumed that graphical detail is one of the most important factors in coordination of design information.

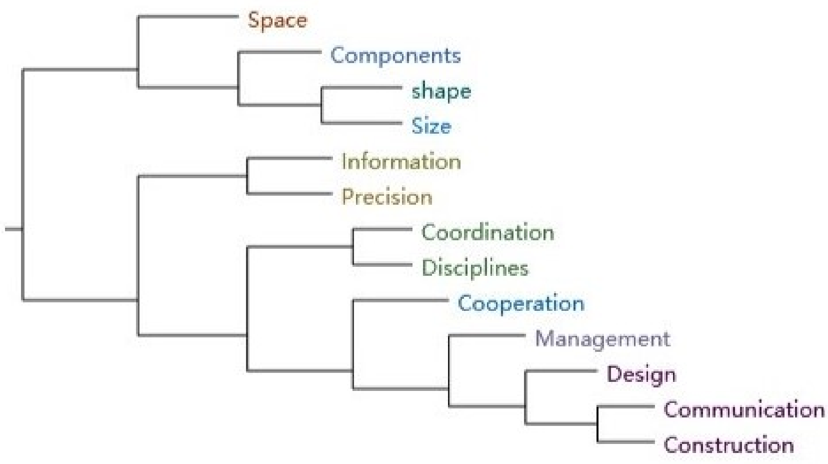


Figure 1.2 a: Clustering Analysis of Factors in Building Design Development (Yang et al., 2020)

The clustering results from NVivo (Figure 1.2.a) show that design is linked with communication and construction, which are related to the management process. Management is linked with cooperation, which shows the impact of collaboration from different design disciplines. Coordination and disciplines are linked, which also cluster with the cooperation process. In this part, the design development process is clustered, which illustrates that communication, coordination, and cooperation are related to each other.

This part shows that cooperation is depending on communication, and then impacting coordination. The design development process is clustered with produced information; the above diagram shows that the precision of information is relying on the performance of design coordination. The components are clustered by shape and size from the aspect of space, and the accuracy of space relies on the precision of the information produced. Therefore, the result from the clustering analysis shows that the quality of spatial coordination depends on the communication from the ground.

According to the findings, the following factors impact information coordination during the building design development:

- ✧ Factor 1: Level of Developments (LOD) impacts design delivery qualities.
- ✧ Factor 2: Efficient collaboration impacts design integration among different disciplines.
- ✧ Factor 3: Good management impacts design production among different disciplines.

Thus, from the identified issues, this research has found that the management process, collaboration process, and detail development process of building information are the key aspects of information coordination. Also, through the data analysis from each discipline, the research has identified that the design information needs to be well shared among different disciplines to avoid potential clashes during the construction stages. The clustering results identify that the collaboration process of building design development will impact spatial coordination of design information. The accuracies of produced information will impact the quality of the coordination process in spatial development, and information precision depends on information management.

In order to further comprehend the interrelation between information requirement, production, and delivery, this research analysed the data collected from architecture, since this is the leading discipline in the building design process (Figure 1.2.b).

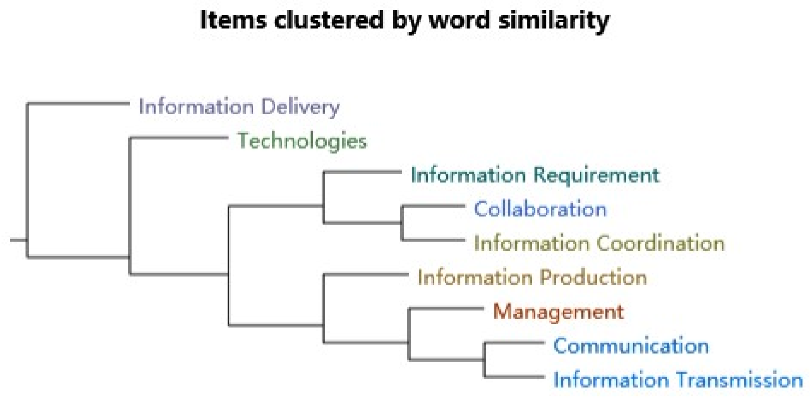


Figure 1.2 b: Clustering Analysis of Factors in Building Design Management

The clustering result (Figure 1.2.b) shows that information coordination and collaboration have the highest similarities, which means that collaboration is closely related to the coordination of design information production. The result shows that communication and information transmission have the highest similarities, which shows that information transmission is related to the communication process.

For better understanding of the identified results, this research has organized the findings (Figure 1.2.c). Three key aspects are organized, the information requirement directs the production of information, and subsequently leads to information delivery. AEC technologies contribute to the requirement and the production of building design information. Information coordination and communication are linked with information requirement for satisfying demand. Collaboration and information transmission are linked with information production for quality assurance.

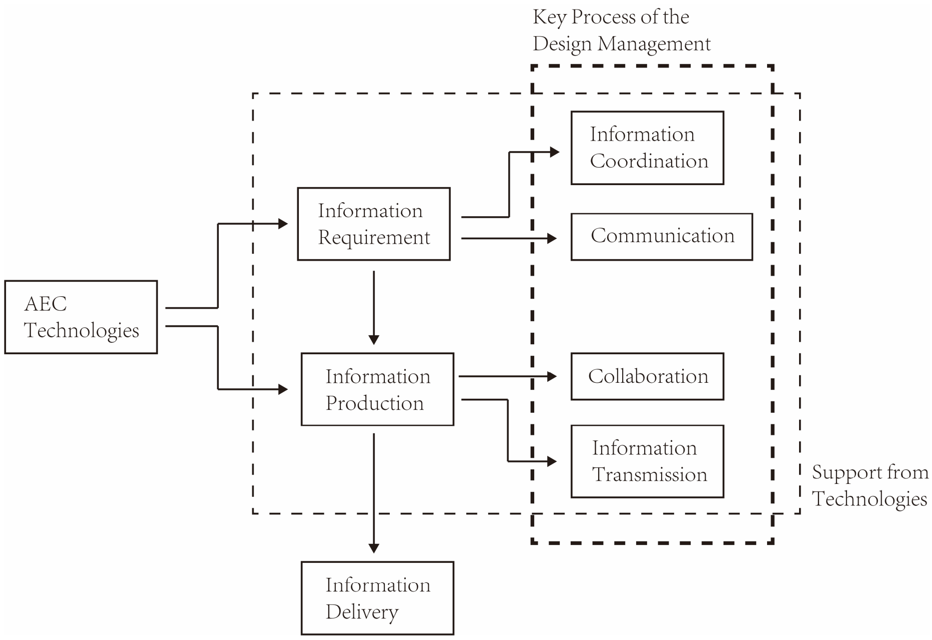


Figure 1.2 c: Interrelations in Building Design Management

The findings show that increased information coordination from the requirement stage will impact collaboration during the production stage, and these aspects are supported by AEC technologies contributing to the design delivery process.

<u>1.2.1.1 Detail Development</u>

In answering the above question, the findings from the semi-structured interviews have identified that the production of building design information needs to match with their actual properties. The findings results have shown that:

- ✓ The geometries of building components need to be sufficiently produced.
- ✓ The accuracies of building geometry and the location of the building elements need to be coordinated.
- ✓ The spatial relation of building components for construction needs to be delivered.

Therefore, in the building design development process, all information of building components needs to be sufficiently produced to support design coordination and delivery for improving the quality of design documents. Hence, through the findings, this research has identified the direction for solving Factor 1, which is to develop the 3D information model with a level of detail to enable integration and coordination.

1.2.1.2 Design Collaboration

Through further investigation of the data, this research has found that the improvement of the communication process can avoid mismatch of the design information. The findings from the interview data show that:

- ✓ Collaboration during design development needs to be accessed with the same information.
- ✓ Collaboration during design development needs to be conducted in a visualized way to coordinate building information.
- ✓ Collaboration during design development needs to be processed in an interactive manner to assess suitability.

Therefore, building design development needs to focus on effective communication for improving the coordination of building information. The communication process contributes to information sharing for correct design production. Hence, with the above findings, this research has shown the direction for Factor 2, which is to adopt the suitable communication method to share design information in an accessible, visible, and interactive way.

1.2.1.3 Information Management

Analysis of the qualitative data has shown that increased information management can impact the coordination process of building design development. The findings show that:

- ✓ The management of building design information needs to be aware of the data exchange process.
- ✓ The management of building design information needs to be aware of data structure.
- ✓ The management of building design information needs to be aware of data storage.

Therefore, the building design development process needs to focus on the data itself. Efficient data management is depending on its storage, structures, and exchanges, which will subsequently impact its information management. Hence, this research has identified a direction for Factor 3, which is focusing on the organization of data.

1.2.2 Supportive Theories and Specifications

1.2.2.1 Information Management under ISO 19650

Based on the PAS 1192 series, ISO 19650 was introduced in December 2018, and proposes strategies to manage information in the development of AEC projects. ISO 19650 is categorized into five parts; the first two parts regulate the principals of information management and the delivery of information. The aim of these two parts is to provide a reference for all project participants as to the correct implementation of BIM. ISO 19650 (attached at Annex) was specifically developed as suitable for different countries and regions. The core aspect of ISO

19650 focuses on the production of structured data throughout the project development for ensuring that project information is produced to satisfy requirements. It highlights the importance of the Information Container and Common Data Environment (CDE) in regulating data storage and exchange. As building becomes increasingly complex, a large quantity of information needs to be correctly managed; the concept of ISO 19650 can be used for managing the produced design information.

ISO 19650 can be used to address poor performance of information management in the AEC sector, fulfilling the global demand for a more sustainable and efficient way of managing AEC projects. The arrival and successful implementation of the Avanti program has led to integration of its core value in BS 1192: 2007, and subsequent merge into ISO 19650. The purpose of the Avanti program is to increase information quality and predictability of results, and to reduce risk. Its method of achieving targets regarding standards, methods, and procedures has been inherited by ISO 19650 for guiding AEC projects to improve information management.

From these aspects, information development according to ISO 19650 involves three stages: information procurement, information planning, and information production. The procurement of information sets up the goal of the project, and the planning of information responds to how to achieve that goal, while the production of information needs to follow the requirements of the procurement and planning stages. The entire process highlights the importance of standards, methods, and procedures (SMPs) with the support of people, process, and technologies. The method of managing design information as specified by ISO 19650 ensures the information is being produced correctly. Therefore, the adoption of the ISO 19650 framework can potentially address the identified issues of information coordination in building design development.

1.2.2.2 Information Development under LOD 350

The model accuracy and maturity level impact the development of BIM-driven projects. However, despite many frameworks intended to guide the modelling process during each stage of design, it is not quite clear how these features at each level impact design coordination and development. The difference between design and model is that modelling is the process of integrating and compiling design information, while design is the process of producing the required information. The quality of the modelling process can help design teams to increase data management and hence to improve design performance. Model development includes the model detail level, which includes both graphical and non-graphical information. The model itself is considered as a database of the building design process.

Moreover, the detail levels of the BIM model need to be examined in a holistic manner to verify its roles and contribution to a building project (Holzer, 2016). The need for information modelling and the importance of ISO 19650 to form and improve the process play a significant role in the implementation of BIM in building design projects. However, there are still gaps in the development of AEC projects; one of the common concerns is how the 3D information model needs to be built and what detail level is required. Level of Development (LOD) was introduced by AIA and has been widely adopted in BIM practice (BIMforum, 2019). The Chinese Department of Urban and Rural Administration regulated Level of Model Definition (LOD) in 2019, which regulated the BIM model from LOD 1.0 to LOD 4.0. In comparison with the AIA standard, there is a missing level equivalent to LOD 350. According to the current BIM practice, most BIM models in building projects jump directly from LOD 300 (design phase) to LOD 400 (construction phase). The workload to develop a BIM model in LOD 400 is tremendously high, according to personal experience in a building design company. Once a mistake is identified, more effort is required in modification.

Evidence has shown that LOD 350 could contribute to the development of building projects in numerous ways, for example, spatial coordination, energy simulation, cost management, etc. LOD 300 is insufficient for spatial coordination during design development and LOD 400 uses too much workload to develop the BIM model. So, there is a gap in between these two detail levels. Despite the existence of LOD 350 since 2013, little research has been conducted to examine its role and functions in building design business operation, according to many literature databases. It is unclear whether and how LOD 350 could impact building design in a holistic way, especially as regards business performance. LOD 350 consists of more features and characteristics than LOD 300, with additional workloads, and it is necessary to inspect this level of BIM model to validate its role from a company's business perspective.

Moreover, with the arrival of ISO 19650, BIM standards have been raised to international level (Shillcock & Cao, 2019a). National and regional BIM regulations is highly recommended to meet the requirements of international standards to win more projects globally (Shillcock & Cao, 2019b). Thus, validation of LOD 350 could improve building design companies' business performance, and in the case of China, could facilitate entry into international markets.

1.2.2.3 Information Collaboration under Gamification

Gamification was first proposed by Nick Pelling in 2002 for increasing the interest of the product. The history of gamification to improve the learning process can be traced back to 1980 (Dale, 2014). With the arrival of personal computers, virtual games were developed for various activities, which speeded up the development of gamification in multiple disciplines. Game can attract people's interests towards an object, thus leading to increased engagement between people and virtual objects (Seaborn & Fels, 2015). Triggers, abilities, and motivations are three pillars of gamification (Claesson, 2017), which use the concept of game in non-game content, according to the mutual agreement of academia in this discipline. The business values of gamification are usability, trust, and motivation (Basten, 2017). Dale (2014) found evidence that gamification can lead to the efficient movement of a company and can increase the engagement of employees to share knowledge.

Nowadays, building design relies on the assistance of a visualized model due to the increasing complexity of its elements. The massive quantity of information may be tedious, which could potentially lead to disengagement and project failure. The concept of gamification can bring the attention of the design team back to design development and make it more fun and attractive, thus leading to better accomplishment of the required tasks (Dale, 2014). Moreover, the engagement from gamification focuses on an emotional level during the development, which can lead to improved performance in achieving outcomes (Dale, 2014). According to Deterding (2012), the wide adoption of gamification is due to the support of available technologies and media. Interaction between people and the virtual environment can be established through gamification (Deterding et al., 2011). Therefore, with the core value of gamification in business operation, building design teams can increase their interaction with design through the virtual environment for better communication and collaboration, which can potentially address the identified issues.

Beyond attractiveness and engagement, another key aspect of gamification is the increased interaction between people and design through the visualized virtual environment. Deterding et al. (2011) highlighted improved interaction through continuous feedback. Building design is a repeat modification process which depends on the client's demand and building codes. The modification is based on evaluation and assessment during the reviewing process. In using gamification to operate building design, this research can foresee that the coordination of design information can be increased due to improved engagement and interaction through the visualized building information.

1.2.3 Findings and Discussions

The preliminary research conducted semi-structured interviews with three AEC disciplines to analyse the qualitative data for identifying the key issues during the coordination of building design information. The clustering results show that poor management, lack of communication, and insufficient development are the main aspects during building design development that are mostly likely to cause the failure of the project. (Table 1.2.a) illustrates the identified aspects from each section of information coordination.

Table 1.2 a: Findings of Factors in Building Design Management

Information Development	Information Collaboration	Information Management
Geometry	Accessibilities	Structure
Accuracies	Exchangeability	Visibilities
Spatial	Interactivities	Storage

Based on the above, this research has preliminarily found the direction for the information coordination during building design development, as follows:

- ✧ Focusing on development of data accuracy for conducting the spatial integration of building components.
- ✧ Focusing on accessibilities of data in a visible environment for conducting interactions.
- ✧ Focusing on the structure of data for exchange and storage.

The development of graphical details needs to be coordinated during the information coordination because building geometry is very important for cross-discipline collaborative production. The size and the shape of each building component are crucial to improve the quality of coordination for optimizing spatial development. The results have shown that building design information needs to be managed to ensure that all graphical data are produced in an accurate way for quality assurance to avoid modification at the construction stage.

Communication of building data needs to be focused on ensuring all project team members have access to the same information. Incorrectly acquired information will lead to incorrect information production, and hence to poor information coordination, which will result in the need for modification or even project failure. Moreover, design information needs to be accessed in a visualized and interactive way to ensure the quality of coordination during design development.

Collaboration in building design data needs to be focused on its structure. How data are being developed will directly impact on coordination quality. The medium and method of data storage will affect accessibilities of required information during design development. Moreover, the organization and the structure of the data will affect the development and integration of building information.

The importance of information development, management, and collaboration has been explored by this preliminary research regarding issues during the coordination of building design information (Figure 1.2.d). The findings show that management of building design impacts the collaboration process, and collaboration impacts information development. The research has identified that information management is focused on data storage, exchange, and structure. The collaboration is focused on understanding, visibility, accessibility, and integration. Also, this research has identified that the accuracy and sufficiency of building information directly impacts spatial and functional coordination, which can subsequently impact the quality of building design.

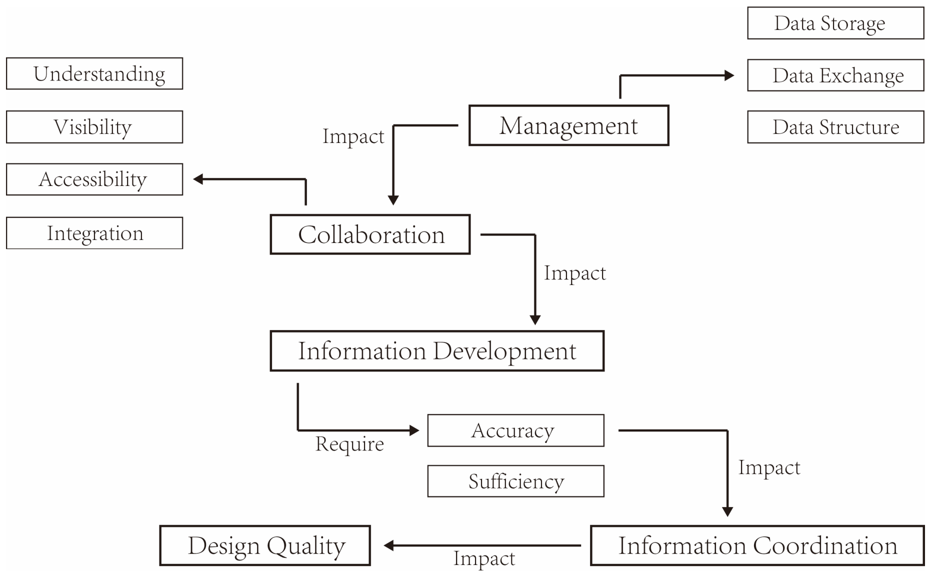


Figure 1.2 d: Factors that Impact Information Coordination

Therefore, this research has preliminarily identified the solution to improve information coordination during building design development, which is to focus on the mutual access to structured data in a visualized and interactive environment for increasing collaboration. The scope of information coordination is focusing on the 3D-based information model during design development. From this perspective, the research has conducted the exploration of those supportive theories in AEC disciplines which can potentially fulfil the above identification. The findings are listed in Section 1.3.

The preliminarily research has identified features from three theories which can be potentially used to improve information coordination during building design development. The five factors which impact information coordination are data accuracy, data sufficiency, data visibility, data exchange, and data accessibility. Their position and interrelation are listed in (Figure 1.2.e). The findings from the semi-structured interviews have shown that the structure of building data impacts the exchange process for integration and visualization, which can subsequently impact the coordination process. The data needs to be stored for access purposes, and data access is the foundation of information coordination.

Therefore, (Figure 1.2.e) shows that data storage is the key that links all the factors for coordination of building design information.

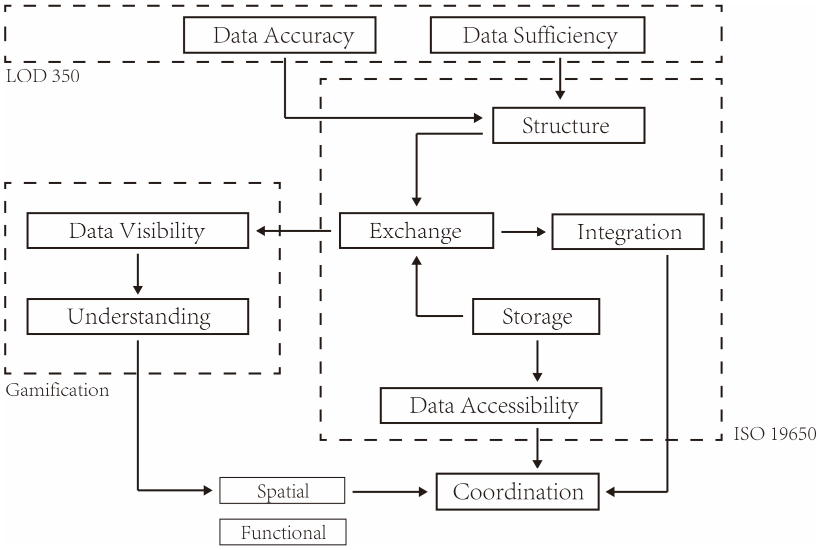


Figure 1.2 e: Findings of Information Coordination in Building Design Management

The core values are extracted from three theories to support addressing the identified issue. ISO 19650 deals with managing the information through structured data development. LOD 350 deals with developing the data to an appropriate detail level, and Gamification deals with improving the interaction between people and the virtual environment. To improve information coordination during the building design, these three theories can be used in an integrative way because this research has found that Gamification requires the support of detailed building visualization data, and therefore LOD 350 can be adopted as a specification to guide the development of the gamificative environment. However, during the data development, an appropriate standard is required to guide its structure, hence, ISO 19650 can be used to fulfil this demand. Therefore, to integrate these three theories for directing this research, information coordination relies on gamification during the business operation to conduct building design development, and collaboration and communication is increased through the gamificative environment to improve building design quality for minimizing waste caused by inefficiency. Thus, the performance of building design businesses can be enhanced.

The interrelation between information coordination and business operation is illustrated in (Figure 1.2.f). The research proposes that building design can adopt a gamificative environment to create immersive and dynamic visualization for conducting information coordination. The establishment of a gamificative environment is depending on the guidance of LOD 350 and ISO 19650 for the implementation of technology. Within the immersive and dynamic visualization, collaboration is increased; hence decision making can be accelerated for improving building design quality. With improved building design quality, so the production of building design is improved, which can subsequently enhance business operation performance.

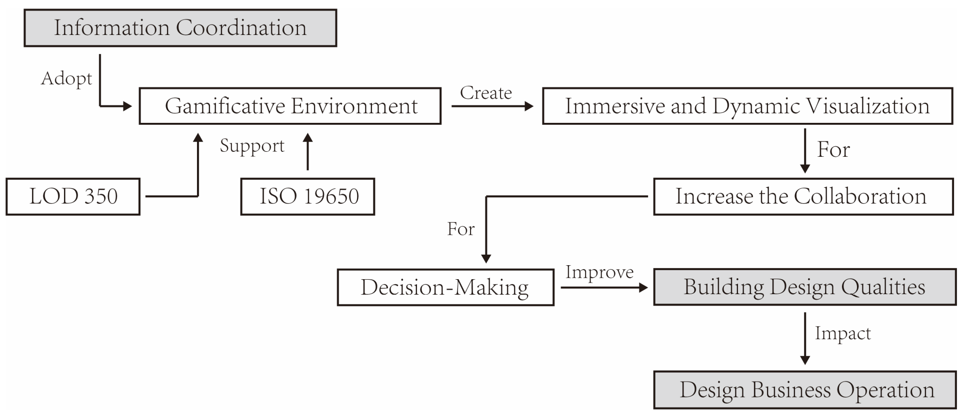


Figure 1.2 f: Findings for Information Coordination in Business Operation

However, despite the integration of these three theories and their potential contribution to information coordination, it is still unclear how they can be integrated to form a new solution to help Chinese building design companies enhance business performance. This research will explore whether and how information coordination can be improved by using LOD 350, ISO 19650, and gamification. Each of these features and characters needs to be studied for matching with the identified issues, then a holistic perspective and understanding regarding their impact on building design businesses will be proposed via a conceptual framework for contribution to knowledge.

1.3 Research Question, Aim, and Objectives

According to the findings, poor information coordination in building design development is caused by a lack of understanding due to insufficient detail, collaboration, and management. The research question developed from preliminarily research is: *Can a Gamificative Environment, achieved through the integration of ISO 19650, LOD 350, and Gamification improve people's understanding in building design review and the evaluation process to increase decision-making efficiencies for enhancing the business operation performance of building design companies?*

For coherent, in-depth exploration, the research question comprises three stages, as follows:

- Stage 1: Can a Gamificative Environment improve people's understanding of spatial and functional information in building project design?

- Stage 2: Can a Gamificative Environment increase decision-making efficiencies during the building design review and evaluation process due to improved understanding of the project?

- Stage 3: Can a Gamificative Environment enhance building design business operation performance due to increased efficiency in decision-making?

The research aim of this study is to investigate whether and how building design information coordination in business operation can be improved by using gamification under the specification of LOD 350 and the criteria of ISO 19650.

For enhancing the business operation of building design companies, the improvement of building design quality is a premise which requires increased information coordination. Information coordination focuses on how information is produced, stored, and accessed during building design development. ISO 19650 gives very clear guidance during the management process of information production, storage and accessibility, while; LOD 350 gives very clear specifications for the development of information production and integration, and Gamification highlights the engagement between people and information production activities.

However, it is still not clear how these three aspects need to be integrated for impacting information coordination in a holistic manner. Therefore, this research will identify the following learning outcomes:

- Objective 1: To **Investigate** the <u>*Issues and Problems*</u> in building design management and information coordination in Chinese Building Design Companies.

- Objective 2: To **Understand** the <u>*Requirements and Specifications*</u> of LOD 350, ISO 19650, and Gamification to increase the information coordination within building design businesses that run BIM-driven projects.

- Objective 3: To **Explore** <u>*Whether and How*</u> the information coordination of building elements can be coordinated within building design business operation through gamificative environment.

The first objective is to target issues, to find gaps, and to propose a new solution;

the second objective is to deal with features of the proposed solution; and the third objective is to make validation for conclusion. The scope of this study is within Architecture, Engineering and Construction (AEC) technologies, and mainly focuses on the design stage of building projects in the Chinese building design market.

1.4 Contribution to Knowledge

The contribution to knowledge of this research is the interrelation between LOD 350, Gamification, and ISO 19650 for enhancing the coordination of building design information. This research clarifies how a 3D information model in BIM-driven projects needs to be produced, integrated, and visualized, for improving the quality of building design from the aspect of information coordination in the business operation of Chinese building design companies. Based on the results of the findings, through investigation and observation, this research proposes a conceptual framework for the design manager to increase the performance of spatial integration through the virtual environment during design development.

This research contributes to both theory and practice. The contribution to theory is in clarification of the role of gamification within the BIM scheme in building design management. The contribution to practice is in providing a new solution for BIM implementation in information production, coordination, and evaluation in building design development.

Increased spatial integration can improve design information coordination, which can subsequently improve building design quality. Key features of LOD 350 have been studied, the role of the gamificative environment has been observed, and the process of ISO 19650 investigated for the innovation of BIM implementation in AEC-related projects to improve the information coordination process. This research has clarified how people, process, and technologies need to be integrated for solving problems in building design. It particularly highlights that those technologies cannot be stand alone; people are needed to follow specific processes to efficiently use these technologies. The proposed conceptual framework provides a reference for addressing these aspects.

Furthermore, the adoption of gamification in the building design process proposed by this research is a new solution for the information coordination process during design development. The created gamificative environment provides a new method using the visualization, evaluation and delivery process for improving understanding toward design. This research clarifies how the gamificative environment needs be created to improve building design quality. In conclusion, the proposed conceptual framework through the integration of LOD 350, gamification and ISO 19650 creates a collaborative environment for enabling the design team, stakeholders, and other project participants to be better involved in building design development for improving project performance. Its contribution to knowledge mainly reflects on providing a direction for how BIM can be implemented in AEC-related projects.

This research proposes a conceptual framework for enhancing information coordination in building design, the quality of building design, and the performance of building design in business operation. This conceptual framework has been constructed based on the following relationship:

- The performance of business operation is based on the capabilities of collaboration.
- A gamificative environment can impact on information coordination, which can increase collaboration.
- Development of the gamificative environment requires an efficient combination of people, process and technology.

The research of this study focuses on the impact of the following aspects:

- ✧ LOD 350 impact on spatial integration during the development of a 3D information model in the building design process.
- ✧ The development of 3D information impact on the establishment of a gamificative environment.
- ✧ An established gamificative environment impact on the interactivities between people and building design.
- ✧ Improved interactivities impact on the coordination of building design information.
- ✧ Increased design information coordination impact on the collaboration capability.
- ✧ Improved collaboration capability can enhance business operation performance.

According to the above relations, three major impacts are identified, as follows:

- ➢ Impact of LOD 350 on spatial integration.
- ➢ Impact of gamificative environment on design interactivities.
- ➢ Impact of information coordination on business operation.

1.5 Research Progress

1.5.1 Framing of the Research

The framing of this research first identifies the problem through background study, then explores the cause of the problem through preliminary research. With a proposed direction, the research goes into precedent studies and a broad review of literature to form a proposition for enhancing business operation in building design companies. The proposition is further examined via action research to develop a conceptual framework, and is validated through focus group and survey. Finally, the new proposed solution is compared with precedent studies, demonstrating its advancement and contribution to knowledge.

The problem identified by this research in background study is: poor information coordination in building design impacts the business operation of building design companies, causing poor design quality and delay in project delivery, which negatively impacts productivity. From these aspects, preliminary research uses semi-structured interviews to collect primary data from AEC professionals for discovering the specific reason behind poor information coordination. Aspects identified through semi-structured interview are: poor information development, management, and collaboration cause insufficient understanding of the building design process, which subsequently leads to poor project information coordination.

For solving the problem and proposing a solution, this research primarily examines literature, exploring three areas which explore the identified aspects: specifications of LOD 350 can guide the design team during information development, criteria of ISO 19650 can help the design team during information management, and the theory of gamification can help the design team during information collaboration. With the integration of LOD 350, ISO 19650, and Gamification, this research has proposed a gamificative environment for increasing information coordination in building design. With the proposed new direction, the research further scrutinizes the literature to evaluate its feasibilities.

This research first systematically reviews how other researchers are addressing information coordination. Through the precedent studies, directions, limitations, and gaps of other solutions are identified. The research then proposes that a gamificative environment integrated with LOD 350, ISO 19650 and

Gamification can potentially fill the gaps in those precedent studies. To further explore the feasibilities that a gamificative environment can impact information coordination in building design management, a comprehensive literature review explores the impact of productivity on business operation, the impact of information development on productivity, and the impact of information management on information development. Features of LOD 350, ISO 19650, and Gamification have been carefully reviewed to discuss whether and how they can impact information coordination. The roles of immersive and interactive technologies are explored to assess their impact on project understanding.

The literature and systematic review use divergent thinking to critically analyse how information coordination can be increased in building design management. The research uses weak evidence to find a rough direction and then strong evidence to further argue its feasibility. With findings from literature and systematic review, the research generated a proposition, which is: "an interactive and immersive visualized gamificative environment integrated with LOD 350, ISO 19650, and Gamification can improve people's understanding towards project development to increase information coordination, therefore, improving productivity and enhancing the business performance of building design companies."

The proposition of this research is a result of divergent thinking, found to be the best way to increase information coordination in building design. To further test if this is the best way, action research is used to evaluate the impact of a gamificative environment. Three intervention studies adopt different gamificative technologies under different scenarios in order to make an evaluation. A conceptual framework has been developed based on the findings from the action research and the impact of the conceptual framework generalized for validation. Finally, this research use focus groups and survey to validate the feasibilities of the proposed conceptual framework.

The research consists of three stages to propose a new direction to increase information coordination. The first stage is a proposition through findings from preliminarily research and literature/systematic review; the second stage is a conceptual framework developed based on proposition and findings from action research; the third stage is the final validation of the proposed conceptual framework. The theory that this research has contributed is gamification, which has clarified its impacts on building design project understanding. The practice that this research has contributed is building design information coordination, which has provided a direction to improve design management.

1.5.2 Thesis Structure

The thesis of this study is organized into six chapters (Figure 1.5.a): Chapter 1 introduces the research background, research motivations and research questions. In this chapter, the research aims and research objectives are detailed, and contribution to knowledge is explained. Chapter 2 explores secondary data through the literature review to make deductive analysis regarding how information coordination can be improved during the building design business operation. A statement of preliminarily conceptual framework from deduction is made for further studies. Chapter 3 gives the research methods for each research objective, which highlights the research paradigm regarding research philosophy and research methodology. Chapters 4 and 5 are primary data analysis for seeking solutions for improving the building design. Specifically, in Chapter 4, the research based on the induction results to develop the conceptual framework is discussed. Chapter 5 finalizes the conceptual framework and identifies the limitations. Chapter 6 is conclusions and research outcomes, and proposals for future research. References and relevant supporting documents for the research can be found at the end of this thesis.

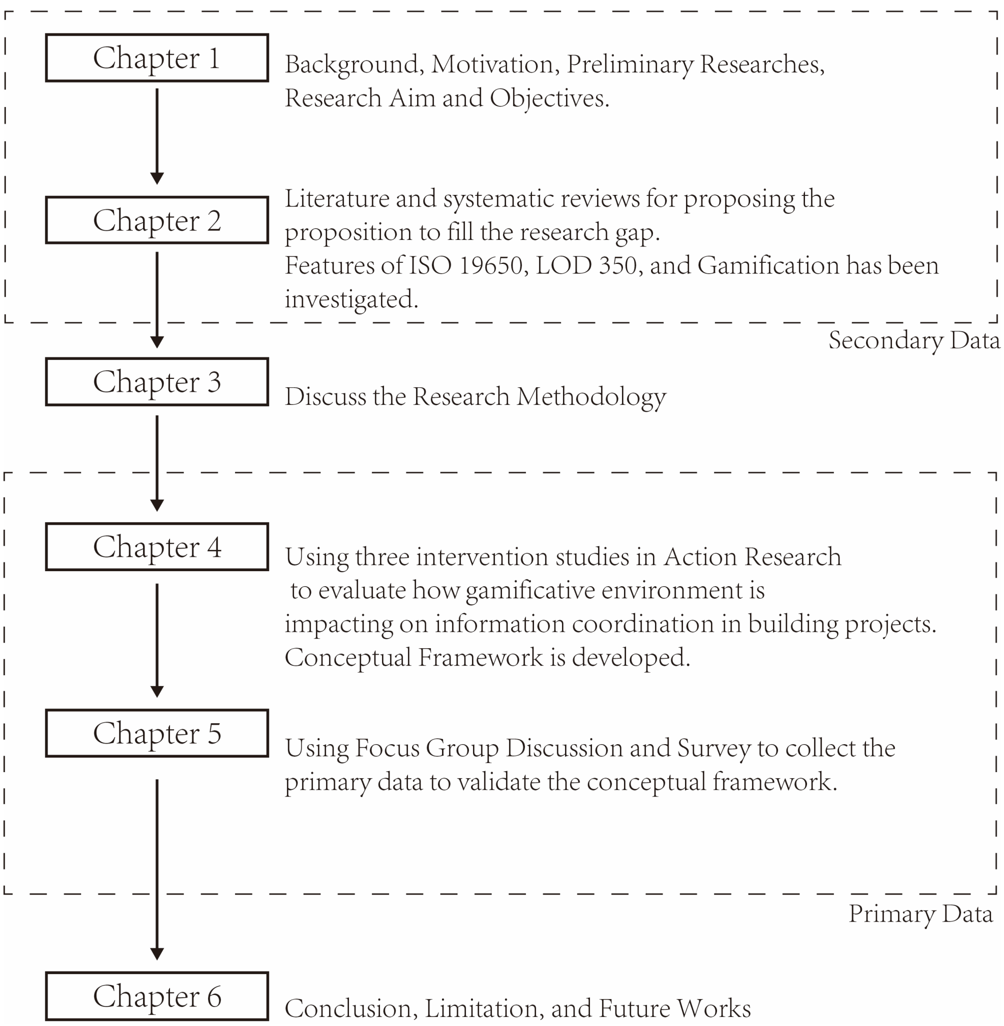


Figure 1.5 a: Thesis Structure

The research progress is organized and conducted sequentially. The findings from each exploration will be continued in a following study. There are three objectives in this research; each objective will impact on the next, and a combination of the three objectives contributes to addressing the main aim of this research study.

1.6 Chapter Summary

This chapter introduces the research motivation, followed by preliminary research to identify the issues and potential solutions. Theories are reviewed to identify research problems, aim, and objectives. This chapter also lists the contribution to knowledge and outlines the thesis structure, which provides a guideline for this research study. The following chapter will discuss the deductive findings according to the exploration of secondary data through literature reviews.

Chapter 2: Literature Review

2.1 Design Data Acquisition and Information Coordination in Practice

Poor information coordination causes a lack of understanding by stakeholders who do not understand project design due to lack of experience, lack of skills in software and technologies, and also lack of familiarity with existing codes and standards in building projects. This leads to miscommunication and misunderstanding between design team and stakeholders on the design documents, leading in turn conflict and placing the business operation under threat. The findings from the preliminarily research show that key factors of information coordination are focused on five areas: Data Accuracy, Data Sufficiency, Data Accessibility, Data Exchangeability, and Data Visibility. For further investigation into how information coordination can be increased in building design, this research formed the following questions:

- ✧ How can ISO 19650 impact data accessibility and data exchangeability during information coordination?
- ✧ How can LOD 350 impact data accuracy and data sufficiency during information coordination?
- ✧ How can Gamification impact data visibility during information coordination?

To address each of the above questions, the research needs to conduct in-depth exploration of:

- ➢ the issues in building design business management and building design business management.
- ➢ the features and characteristics of LOD 350, ISO 19650, and gamificative

environment.

- the interrelation between information coordination and building design business performance.

Information coordination in building design deals with how a project participant is producing, sharing, and accessing information during the development process (Czmoch & Pękala, 2014). It is in a way more relating to project collaboration (Eynon, 2013). The large amount of produced data needs to take management down the appropriate route to ensure correct project delivery (Arayici et al., 2011a). Inappropriate information coordination will cause chaos during design development, ending in project failure (Taylor, 2000). Although the importance of design coordination is now being acknowledged, in spite of best efforts, due to the limitation of traditional methods, many issues are still unresolved.

Information coordination in building design development is not always efficient; despite the existence of communication tools such as computers and mobile devices, the collaborative process faces numerous problems (Eynon, 2013). Unsuccessful management of building design information results in wastage of resources and lowering of production efficiencies, which negatively impacts the design business operation (Rounce, 1998). Due to multiple unforeseen incidents and factors, building design information is difficult to manage (Knotten et al., 2015). According to the preliminarily research, the issues identified during design development are poor collaboration, poor communication, and lack of detail. Hence, the focus on this literature review is exploring the impact caused by these three issues.

Insufficient communication between design team and clients is one of the problems effecting design developments (Knotten et al., 2017). Design outcomes that do not meet client expectations will require modification and thus cause project delay (Best, 2006). The reasons for poor communication are many;

according to literature reviews, clients cannot understand the diagram because they do not have a background in AEC (Norouzi et al., 2015); project demand is unclear during the planning and programming phase (Yu & Sangiorgi, 2018); there is difficulty in satisfying all demands from different stakeholders (Laing et al., 2017); project demands contradict local building codes (Imrie, 2011).; and project budget exceeds functional demand (Knotten et al., 2017).

Inefficient collaboration within design teams is another significant factor in problematic design development (Pikas et al., 2018). Enabling different design disciplines to fully understand each other's work is a complicated matter (Elmualim & Gilder, 2014); the priority and order of different disciplines are different during the design process (Knotten et al., 2017), while it is difficult to deliver information and data produced by one discipline simultaneously with another discipline (Best, 2006). As a result, information delay is a common problem in building design (Rose, 2013).

Insufficient detail will cause a lack of solutions in integrating comprehensive information in the building project, which will likely cause failure of building design (Cao et al., 2015). Traditional management methods are unable to deal with a large quantity of information from different sources (eg., client demands, stakeholder requests, design team output, local building codes), resulting in insufficient data integration (Liu et al., 2017). According to personal observations, many building design companies are still using 2D-based design software with uncoordinated information, and data integration is mostly according to the design team's subjective experience rather than subjective analysis (Knotten et al., 2017). Subsequently, errors occur frequently during the construction phase, requiring modifications (Rounce, 1998). Moreover, 3D design is not well coordinated with 2D drawings, causing numerous spatial problems (Peckienė & Ustinovičius, 2017).

The findings from the secondary data regarding the impact of poor information coordination at each stage of building design development are listed in (Table 2.1.a). The research has identified the four stages of design that are most impacted by information coordination: design planning, production, evaluation, and delivery. There are three main issues explored in the literature review: insufficient communication, insufficient collaboration, and insufficient detail. Insufficient communication is likely to affect the planning and evaluation stage of the building design, insufficient collaboration affects the production and evaluation stage of building design, and insufficient detail impacts on the evaluation and delivery stage of design development. The findings from this section will be used for seeking the solution to integrated LOD 350, ISO 19650, and Gamification during BIM implementation in Chinese building design companies.

Table 2.1 a: Findings of Impact of Poor Information Coordination

	Design Planning	Design Production	Design Evaluation	Design Delivery
Insufficient Communication	√		√	
Insufficient Collaboration		√	√	
Insufficient Detail			√	√

Based on the findings, this section identifies those key aspects during the coordination of project information and explores the factors that need attention in the development of an AEC project. This section systematically reviews literature to explore how other research deals with information coordination in AEC projects. More than 500 pieces of literatures are reviewed, and this research classifies them as follows: information management, AEC technologies, and regulations. The method of selecting and filtering literature is detailed in Chapter 3.

The following sections, from 2.1.1 to 2.1.3, present the findings of the systematic review regarding improvement of information coordination from the perspective of management, technologies, and standards. Through the review of the filtered literature, this research has found that increased information coordination can positively impact project management. The solution to increasing information coordination mostly focuses on using technology to increase interaction via the visualization process by following certain processes to integrate the design model. Most codes and standards regulate the development to improve production of information and how the design needs to be integrated.

2.1.1 The Management Perspective

The management of the building design has a high impact on design production because it coordinates the required information to ensure successful design delivery (Imrie, 2011). For this part, this research filtered 27 pieces of literature regarding solutions for information coordination. As found from the literature review, the most important three aspects in information coordination are, Collaboration, Integration, and Communication. The findings from the literature, are listed in (Table 2.1.b). The statistics show that almost all the selected literature mentions integration in design management.

Table 2.1 b: Literature Review of Information Management

Research	Focus	Collaboration	Integration	Communication
Rounce (1998)	Process		√	√
Best (2006)	Strategy	√	√	√
Knight, Roth, and Rosen (2010)	Process	√	√	
Arayici et al. (2011)	Strategy	√	√	√
Singh, Gu, and Wang (2011)	Strategy	√	√	√
Hu (2012)	Strategy		√	
Emmitt (2013)	Strategy	√	√	√
Czmoch and Pękala (2014)	Strategy	√	√	√
Elmualim and Gilder (2014)	Strategy	√		√
Porter et al. (2015)	Process	√	√	√
Alharbi, Emmitt, and	Process	√	√	√

Demian (2015)				
Knotten, Svalestuen, Hansen, and Lædre (2015)	Process	√	√	
Mäki (2015)	Process	√		√
Oh, Lee, Hong, and Jeong (2015)	Strategy	√	√	√
Malak Al Hattab and Hamzeh (2015)	Process	√		√
Juszczyk, Tomana, and Bartoszek (2016)	Strategy		√	
Tauriainen, Marttinen, Dave, and Koskela (2016)	Process	√	√	√
Wang and Gao (2016)	Process	√		√
Peckienė and Ustinovičius (2017)	Strategy		√	
M. Al Hattab and Hamzeh (2017)	Process	√	√	√
Liu, van Nederveen, and Hertogh (2017)	Strategy	√		√
Sanches (2017)	Process	√	√	
Pikas, Koskela, Treldal, Knotten, and Bølviken (2018)	Strategy			√
Uusitalo, Seppänen, Peltokorpi, and Olivieri (2018)	Process		√	
Aguiar, Vonk, and Kamp (2019)	Process		√	
Ingram (2019)	Strategy		√	√
Tafraout, Bourahla, Bourahla, and Mebarki (2019)	Process		√	

As identified through reviewing the selected literature, this research has found that most solutions for improving management focus on processes and strategies. This shows that Standard Methods and Procedures (SMPs) are important in improving information management in building design. These SMPs contribute to collaboration, communication, and integration for enhancing information coordination in building projects. Therefore, through the findings, this research suggests that through the combination of appropriate SMPs during building design development, information coordination can increase due to improvement of the executive process.

2.1.2 The Technological Perspective

According to the relevant findings from literature review, technology plays a significant role in helping project teams to increase information coordination through advanced production tools. For this research, 21 pieces of literature were reviewed, which discussed how State-of-the-art AEC technology contributes to information coordination. The findings in the literature review identified three important aspects: immersive, interaction, and visualization (Table 2.1.c). Through exploration of the selected literature this research found that most technical solutions are discussion interaction and visualization; therefore, the visualized interactive environment is being considered as an effective solution for improving the coordination of design information.

Table 2.1 c: Literature Review of AEC Technologies

Research	Technologies	Immersive	Interaction	Visualization
Du, Liu, and Issa (2014)	Cloud-based		√	
Isikdag (2015)	IoT-based		√	
Rodriguez-Gil, Garcia-Zubia, and Orduna (2016)	VR-based	√	√	
H.-S. Kim, Sangmi, Sunju, and Kang (2017)	AR-based			√
Roper (2017)	VR-based	√		√
Motamedi (2017)	VR-based	√	√	√
Li, Ch'ng, Cai, and See (2018)	VR/AR-based	√	√	
Du, Zou, Shi, and Zhao (2018)	Cloud-based VR		√	√
Du, Shi, Zou, and Zhao (2018)	VR-based		√	√
Lin, Chen, Yien, Huang, and Su (2018)	VR-based		√	√
Zaker and Coloma (2018)	VR-based	√	√	
T. Kim (2018)	Gamification		√	√
Yu and Sangiorgi (2018)	Gamification		√	√
Pour Rahimian, Chavdarova, Oliver, Chamo, and Potseluyko Amobi (2019)	Virtual-based			√
Pratama and Dossick (2019)	VR-based	√		√

Aparicio, Oliveira, Bacao, and Painho (2019)	Gamification		√	
Deterding (2019)	Gamification		√	√
Thorpe and Roper (2019)	Gamification		√	
Friedrich, Becker, Kramer, Wirth, and Schneider (2020)	Gamification	√	√	√
Holly, Pirker, Resch, Brettschuh, and Gutl (2021)	VR-based	√	√	√
Kim, Lee, and Bovik (2021)	VR-based		√	√

The findings from literature show that many solutions to the issue of information coordination are focused on Virtual Reality, due to its ability to provide an immersive environment to enhance the experience of project participants. For the solution of interaction, some literature argues that through the adoption of gamification, people are more willing to engage. The Internet of Things (IoT) is a technology that links devices and facilities to build a comprehensive system for people to be involved, which focuses on the connection of the hardware. Thus, this research suggests that through the interrelation between immersive and interactive technologies through the combination of various hardware, information coordination can be efficiently increased because humans are motivated in such an environment.

2.1.3 The Codes and Standards Perspective

Building codes and regulations reflect the criteria and research outcomes at governmental level. Research filtered the regulations and specifications shown in (Table 2.1.d). The literature details which rules building design needs to follow and which specifications BIM is required to implement through the building project development. According to the literature review, this research has identified three criteria regulated by the building and BIM codes: Procedure, Methods, and Management (Table 2.1.d). It is found that most standards and specifications focus on management strategies regarding the coordination of design information.

Table 2.1 d: Literature Review on Codes and Standards

Codes	Regulation	Procedure	Methods	Management
MOHURD (2005)	Design			√
ISO (2012)	Information	√	√	√
ISO (2012)	Information	√		
ISO (2013)	Assets			√
NIST (2015)	Information			√
ISO (2016)	Information		√	
MOHURD (2016)	Information	√		√
MOHURD (2017)	Information	√	√	√
NIBS (2017)	Information	√	√	√
ISO (2018)	Information	√		√
ISO (2018)	Information	√		√
MOHURD (2018)	Information	√	√	√
NBS (2018)	Information	√		√
ZJ-DHURC (2018)	Information	√	√	√
NBS (2018)	Assets			√
AIA (2013-2019)	Information			√
China BIM Report (2018-2020)	Information			√

The findings show, according to the regulations, the importance of information management. In recent regulations for AEC industries, the criteria focus more on the coordination of information in project development. These regulations contribute to the process of design management and provide direction for the relevant methods and procedures. As the entire industry moves forward to the digital era, this research argues that following the process of information management instead of the traditional way can significantly enhance information coordination during the development of building projects.

2.1.4 Findings and Discussions

The findings from the management, technological, and standards parts direct this research to focus on integration, interaction, and management in information coordination of design development. The research has found that collaboration impacts the integration process, that visualization technologies impact interaction, and that the procedure from regulations will impact the entire management strategy. (Figure 2.1.a) shows the aspects identified for the next step of the research. This research argues that the management of integration through interaction has the potential to increase information coordination. These three focus on three different levels of aspects.

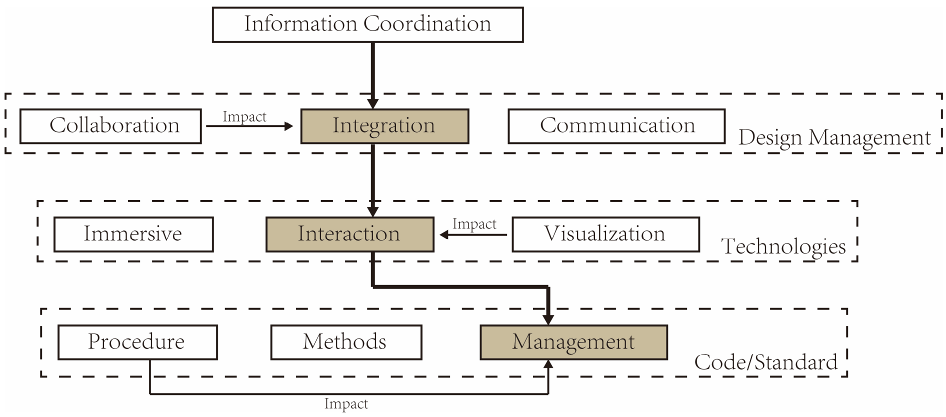


Figure 2.1 a: Mapping Management - Technology - Standards

The selected literature details relevant technologies and solutions to improve management of AEC-related projects, which have an equivalent effect on building design projects. The outcome of the literature studies has positive results; it proves that increased information coordination can improve the quality of design management. This research identifies that integration, interaction, and management in the coordination of design information are important aspects which need to be further studied for finding solutions to enhance building design management. (Figure 2.1.b)

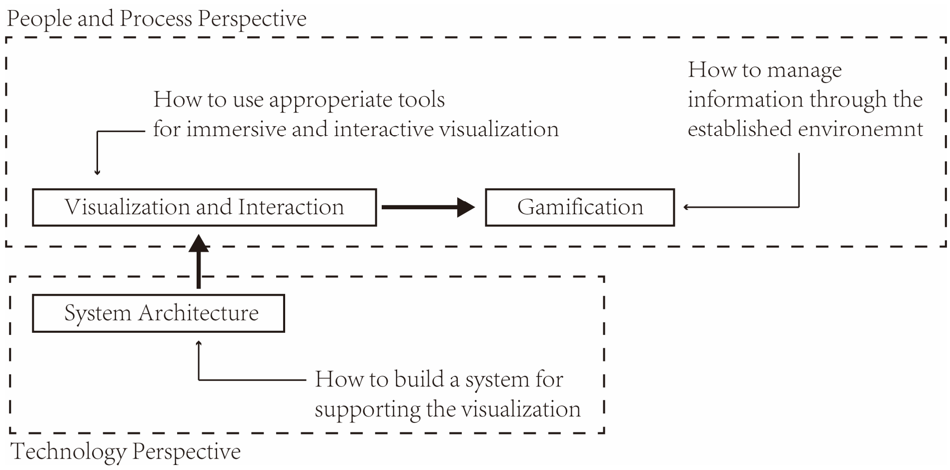


Figure 2.1 b: Identified Gaps of Information Coordination

The systematic review explores the field of building design management in the AEC discipline filtering literature relating to the impact of improved information coordination on the performance of design management. The research investigates the key aspects in coordination of design information based on three different categories of literature. The findings from the management aspect show that information coordination needs to focus on integration; the findings from AEC technology show that information coordination needs to focus on interaction; and the findings from standards shows that information coordination needs to focus on the management aspect. Therefore, the conclusions from the systematic review are:

✧ The information needs to be integrated during design coordination among the collaboration between different disciplines.
✧ The information needs to interact with project participants through the visualization process throughout the modelling development.
✧ The information needs to be properly managed by using relevant codes and standards through following SMPs during the coordination process.

By using these three findings, this research has identified the essentials of information coordination in building design management. Therefore, the potential solutions to improve design quality are directed to improve the integration process through visualized interaction by following the relevant specifications. Therefore, a gamificative environment that consists of immersive, interactive and visualisation capabilities might facilitate better information coordination in building design practices. However, despite the direction identified, it is still unclear how information needs to be integrated. This is an element that will be further considered in answering Objectives 2 and 3, as listed in Chapter 1. Section 1.3 (**pp. 42**).

2.2 Team Productivity and Business Operation in Design Practices

The successful business operation needs to create a competitive business strategy (Mariotti, 2012). The term "Business Model" is defined as maximizing the clients' value through forming a competitive operation system by integrating companies' resources and optimizing the working process (Longenecker, 2003). The business model is one part of the business strategy (Slywotzky & Euchner, 2015) and is the means by which an enterprise makes money (Leone, 2009). There are two main types of business models that a company can implement: the operating business model and the strategic business model (Spencer, 2013). A company needs to comprehensively understand its position in the market to formulate an efficient business model (Gerdoçi et al., 2018). Since business model implementation is part of business operation (Simon et al., 2014), the success of business model design is very important. Business operations need to consider the companies' development in the short, medium, and long term (Coyner & Kramer, 2017). According to literature reviews, it takes time for companies to balance investment with revenue (Zott & Amit, 2010); hence, a clear vision needs to be provided by business management for efficient decision making.

A company needs to focus on specific management areas during the business operation (Norman, 2017). Business management is a very comprehensive process where multiple elements and factors need to be taken into consideration (Saunders et al., 2020). Different companies provide different services which rely on the input of different resources (Airey, 2013). Design companies rely on the input of human resources (Knackstedt, 2012) while construction companies rely on cash flow (Bryde, 2008). Therefore, for example, design companies need to focus more on human capital management and construction companies need to focus more on financial management. Core capabilities, cost structure, and revenue model are three important components in business model development (Gerdoçi et al., 2018). Design companies rely more on core capacities while construction companies depend on cost structures to run the business operation. Core capabilities include management competence, technological competence, and marketing competence (Teece, 2010) A company needs to understand its strengths and weaknesses during the business operation (Airey, 2013), since focusing on the most important aspect can help a company create a successful business model.

The business model canvas (Table 2.2.a) was proposed by Alexander Osterwalder in 2010 from the book, Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, published by John Wiley & Sons P&T. The business operation has been categorized into nine elements for the development of a company's business model, which is shown in the following table. The Business Model Canvas is a very useful tool for planning the long-term development strategies of a business operation (Joyce & Paquin, 2016), and its core purpose is to provide a practical solution for companies to survive in the market (Jin et al., 2021). In recent years, building design in the Chinese AEC market is increasing, as many companies are qualified to operate in this sector. Hence, business managers in design companies need to think how to avoid failure, then how to lead the company in becoming successful in the building design market.

Table 2.2 a: Business Model Canvas (Osterwalder, 2010)

<table>
<tr><td rowspan="2">Key Partners</td><td>Key Activities</td><td rowspan="2">Value Proposition</td><td>Customer Relationships</td><td rowspan="2">Customer Segments</td></tr>
<tr><td>Key Resources</td><td>Channels</td></tr>
<tr><td colspan="2">Cost Structure</td><td colspan="3">Revenue Streams</td></tr>
</table>

This canvas covers four major aspects of business operation: Clients, Products, Facilities, and Finance. For clients, there are two types: To Business (To B) and To Customers (To C). According to market research into building design, clients of most building design businesses are To Business, which means, clients are from industry or public sectors. The Product which designs companies provide is building design documents, which covers planning to detailed construction documents. The Facilities operated by building design companies are mainly computers and software for producing the design documents. For the Financial aspect, the income of design companies is mainly design fees based on a fixed-price contract, and the cost of design companies is mainly employee salaries, while utilities bills account for only a small portion. (Table 2.2.b) shows the relations between each element in the business model canvas.

Table 2.2 b: Elements in the Business Model Canvas

Clients	Customer Relations	Single-Contract from bid, or long-term collaboration with real estate developers
	Customer Segments	Industries, Public Sectors
Products	Key Activities	Building design along the entire design stage, from consultation, planning, and detailed design.
	Value Proposition	To distinguish in design performance
Facilities	Key Resources	Human capital and IT equipment
	Key Partners	Third-party technical supporting companies
	Channel	To promote the design
Finance	Cost Structure	Salaries of employees
	Revenue Stream	Fixed-price contract

The question raised here is what core capabilities does the design team have, and how do they relate to design document production; this is discussed in the

Section 2.2.1 and Section 2.2.2.

2.2.1 Design Team Core Capabilities and Design Document Production

The term productivity was proposed by Francois Quesnay (1694-1774), and subsequently studied and developed by Adam Smith (1723-1789) for enhancing its meaning as regards economic wealth. The modern theories of production in industrial society as raised by Friedrich Liszt (1789-1846) highlighted the importance of productivity at national level. According to the theories of productivity throughout history, the factors impacting production have three aspects: Maturity of Labour Skill, Technology Development Level, and Technological Application Level. It is widely acknowledged that science and technology can impact production capability. Therefore, modern studies of productivity involve research of production technology (technical-oriented) and research of production methods (theories-oriented). The improvement of productivity is classified as short-term, medium-term, and long-term (Syverson, 2011). Short-term development is not focusing on substantial factors, while long-term development is focusing on strategical development of production from technological and methodological aspects (Cardinale et al., 2009). Therefore, long-term strategic development can substantially solve issues for improving the production capability of a building design company. Since the building design company has limited capability to focus on researching technology, business operation needs to focus on methodological aspects to discover how different existing technologies can be utilized.

Improvement of core capabilities can potentially increase design team productivity, and the adoption of BIM brings new SMPs to design companies that could improve the design management process. According to findings from literature reviews, BIM model development could be improved through implementation of LOD, ISO 19650, and Gamification. Core capabilities consist of management, technology, and marketing (Spencer, 2013). Building design companies need to increase their core technology capabilities to improve productivity. This technology comprises core research capabilities and core production capabilities (Laszlo, 2013). Design company products are service based (Eynon, 2016), with project consultation (surveys and feasibility studies) and design documents (engineering and construction instructions) being two of the major deliveries. Design company research capabilities are beyond the scope of this study; hence, this section will discuss how to improve core technology capabilities from the production side.

In Section 2.2, the business model canvas was discussed. This research argues for the improvement of design companies' business model from three aspects, which are, Key Activities, Key Resources, and Value Proposition. According to this research, based on the business model canvas, Key Activities and Key Resources are categorized as Production, which is being particularly highlighted during production development. From the literature review of business management, this research targets Core Capabilities to propose the solution for improving business performance, since Core Capabilities are considered as the qualification and ability of a company to run a business (Leonard, 1992). Core Capabilities are categorized into four levels, according to the enterprise strategy research by Wei (2009) (See Table 2.2.c - Table 2.2.e); the interrelation between the first two levels is illustrated in (Table 2.2.c).

Table 2.2 c: Summary of Level 1 and Level 2 of Team Core Capability

Level 1	Level 2	Notes
Team Core Capabilities	Team Core Management Capabilities	The ability to control the overall strategies of the business operation.
	Team Core Production Capabilities	The ability in research and production of the business operation.
	Team Core Marketing Capabilities	The ability to promote the company's business and product in the market.

For building design businesses in the Chinese AEC market, this research argues that increasing the core production capabilities can help to improve the company's business performance. The reason that this research focuses particularly on this area is that the management in building design companies is unlike many other businesses; the major activity in design businesses is design production based on the relevant requirement. Despite the importance of other management, design production management is the most significant for business operation. Since most projects in design companies do not require marketing promotion, only core production capabilities from the second level of core capabilities are the focus of this research. The relation between the second and third levels of teams' core capabilities are illustrated in (Table 2.2.d).

Table 2.2 d: Summary of Level 2 and Level 3 of Team Core Capability

Level 2	Level 3	Notes
Team Core Production Capabilities	Technology Research Capabilities	The ability to research and to innovate technologies.
	Product Manufacturing Capabilities	The ability to produce the product.

According to the literature review, core technology capabilities are categorized into core research capabilities and core production capabilities. Since design companies are not research-based institutes, the major activities of the business use current available technologies to produce the building design. Therefore, this research is focusing on how to establish the interrelation between product manufacturing capabilities and business operation performance. For each part of the specifications, there are four levels. (Table 2.2.e) shows the interrelation between the third and fourth level of core capabilities.

Table 2.2 e: Summary of Level 3 and Level 4 of Product Core Capability

Level 3	Level 4	Notes
Product Manufacturing Capabilities	Advanced Production Technologies	Advanced technologies being used in building design development.
	Flexibilities in Production and Manufacturing	The flexibilities to change production.
	Abilities to Control the Production Qualities	The capabilities to ensure the design quality meets expectations.

	Abilities to Control the Production Cost	The capabilities to control the cost during the design process.
	Ability to Control the Production Schedule and Stabilities	The capabilities to ensure the design documents can be delivered on time.

There are five categories in total in the fourth level of core capabilities of the business model, each playing an important role in business operation. According to the research and observations of design companies, this research has identified that three items from the fourth level in core capabilities need to be improved for increasing Product Manufacturing Capabilities: Advanced Production Technologies, Ability to Control the Production Qualities, and Ability to Control the Production Schedule and Stabilities. The other two are not being considered because building design companies do not need to change product type and the production cost is relatively constant. The proposed three items are being considered for ensuring the quality and efficiencies of the current production. This research argues that these three items have significant room for improvement in terms of enhancing the performance of business operation.

As identified, the core production capability of building design is split into three parts by this research: advanced production tools, quality control, and schedule control. The technology adoption innovation impacts the advanced production tool, and the process innovation impacts the quality and schedule control. Therefore, the entire production capability of a building design company impacts the issue of labour. According to personal working experience in a building design company, design involves repetitive modification during design development. For most of the design project, the client's payment is not hourly but through a fixed-price contract (Eynon, 2013). Although modification is part of the design process (Imrie, 2011), frequent design changes affect productivity. For example, the design team cannot focus on the next project without first completing the current one. Therefore, projects will be queued, causing a delay in design delivery and affecting future business. Design companies need to identify those factors that cause excessive modification and find strategies to resolve them. According to literature reviews, those factors include not meeting clients' expectations during concept design (Eynon, 2013), disciplines not well coordinated during design development (Taylor, 2000), and the project not meeting building codes during design delivery (Hattab & Hamzeh, 2016). Although there will always be tough clients, most design modification can be avoided, according to personal industrial experience. Hence, to improve productivity in design companies, the frequency of design modification needs to be minimized.

According to personal industrial experience, the design evaluation process is not always efficient. Prior to delivery to the client team, the design must pass internal assessment to ensure that the design quality meets all the client's requirement and building codes (Imrie, 2011). Following the internal assessment, external teams such as clients and stakeholders will evaluate (Ciribini et al., 2016) and, once completed, the design documents must be submitted for government approval (MOHURD, 2005). The efficiencies of the evaluation process determine the productivity of design companies. According to RIBA and Chinese building codes, there are two major design assessments during the whole design phase, one after the concept design and the other after the construction documents design. The evaluation of the concept design includes building size, functions, usage, and appearance, while the evaluation of construction documents includes all construction specifics, according to "Design Document Depth Regulation (2021)." Both evaluations have certain difficulties during the assessment, for example, concept design must satisfy functional and aesthetic requirements, while construction documents must coordinate different data from each discipline. There is a high demand for design companies to find a way to speed up the evaluation process.

The design evaluation process is inefficient because of inadequate design presentation methods (Rounce, 1998). Inefficient project evaluation will consequently cause the delay of design delivery. According to the findings, design companies need to improve this situation through increasing their product delivery control capabilities. Design teams consist of multiple disciplines, and different disciplines have their own professionality (Imrie, 2011); a person in one discipline cannot fully understanding the design output from another discipline, for example, structure, MEP, and HVAC are beyond architects' knowledge. This causes confusion during the design coordination process. Similarly, during the design evaluation stage, if the assessment is based on professional design documents, the process is not straightforward enough. Sometimes it is difficult for non-professional people to read 2D-based symbols, especially in MEP and HVAC design documents (Eynon, 2013). Hence, an efficient method is required to coordinate those design documents into an understandable format. In this way, people from different backgrounds can better collaborate to assess a building project. So, considering (Kapogiannis et al., 2018) a collaborative culture should consider also integrated and collaborative technologies that will enable project managers to develop proactive behaviour (Kapogiannis et al., 2021).

Therefore, Gamification and Gamification Theories that direct a gamificative environment to help people's understanding of a building design project need to be considered. Petridis and Lauren Traczykowski (2021) gave various examples of how game, simulation and gamification add value to organisations because of the direct involvement of decision makers. Qualitative data from a preliminary study carried out by this research showed that design team and clients in Ningbo for a Tier 1 design studio found a gamificative environment helped to better understand the building, as well as construction and investment risks (See Figure 2.2.a). For details, see Intervention Study 1 in Chapter 4, Section 4.2.1 (**pp. 253 - 273**).

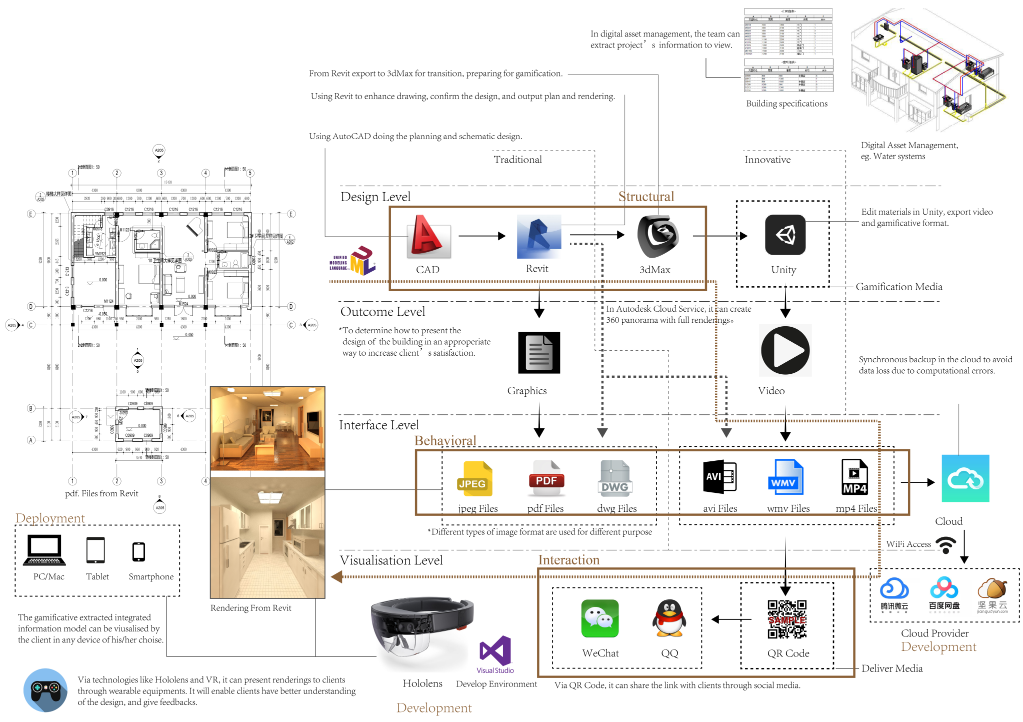


Figure 2.2 a: A Gamificative Environment for Building Design Information Coordination

Consequently, the researcher considering that BIM paradigm (Eastman et al., 2011) is considered as the geometrical representation of a 3D model that according also the Petridis and Traczykowski (2021) could be considered as a visualisation tool that by integrating details could really offer advanced design building models with valuable data. Thus, BIM as is aimed at establishing a visualized information management solution for collaborative purposes (Eastman et al., 2011) then this research proposes that through integration of BIM and gamification, an information-based gamificative design environment could be created to increase information coordination within design business. This could happen due to the design team can increase their core capabilities and thus control the documents design development process in a more comprehensive way as is highly recommended by Koskela, Kiviniemi and Egbu.

Therefore, problems such as repetitive design modification due to lack of data coordination (poor design outcomes) during each stage of the design process

(Alharbi et al., 2015) could be avoided since improved design team core capabilities allow better control of the process by developing proactive behaviour (Kapogiannis at al., 2021). Further, since poor information management is a cause of multiple errors, such as spatial clashes and functional misplacement, resulting in chaos and inconsistency in project development (Porter et al., 2015), gamification could eliminate uncoordinated data that cause misunderstandings between different disciplines (Arayici et al., 2011a). Hence, since efficient solutions are required to manage data during the entire design process (Fagan, 2019), the immersive - integrated - visualised gamificative environment could help to run serious games and simulations to manage data during the design process (Petridis and Traczykowski, 2021).

Moreover, through a collaborative environment, lean management can improve product quality (Koskela et al., 2019), whilst a collaborative culture in AEC sectors will improve KPI (Kapogiannis, 2013). BIM is aimed at improving the collaboration process during building project development (Eastman et al., 2011), and its information modelling process according to ISO 19650 provides information management strategies (Shillcock & Cao, 2019a). Therefore, this research suggests establishing an efficient workflow through integrating the theories of collaborative culture and information management for improving the design team's control capabilities over a gamificative environment.

Improving team quality control capabilities ensures that building design meets all relevant requirements of both client and building codes. On this basis this research proposes that through the adoption of an immersive gamificative environment to visualize the design production, the coordination and evaluation process of the design assessments might be approved in an efficient way.

The quality control of building design is categorized into two parts: whether the design meets all functional perspectives (including exterior appearance and interior space) and whether the design meets all building regulations (including technical construction and post occupancy usage). So, under this hypothesis the research could validate that visualization strategies implemented through a gamificative interactive environment might increase design information coordination, which subsequently can improve design management.

Consequently, improved design quality will make clients aware of the added value of the project from the design phase, since the design team's information model will allow clients to foresee the potential of the project beyond the design phase, such as how the project can be constructed and utilized through serious games and simulations. Hence, this research initially links quality control capabilities from core capabilities with value proposition from the business model.

Due to the increasing complexity of modern buildings, the efficiencies of design production depend on information integration and coordination. Hence the need to adopt information management standards such as ISO 19650 to improve design team capabilities in terms of controlling the flow of the information development process, thus enhancing efficiency during information production. The established CDE and information hierarchy cascade will provide the design team with a reference regarding how information needs to be processed and transferred (Patacas et al., 2020). Therefore, as presented earlier in this chapter, the researcher takes into consideration ISO 19650 aiming at performance design efficiency, improved through a gamificative, interactive and integrated environment. Information management strategy in a design company is considered as one of the most important activities (Uusitalo et al., 2019). Hence, this research links team production control capabilities with key activities from the business model to produce an improved version of the model: the proposed conceptual framework. (Table 2.2.f) shows the connection between key elements and production capabilities.

Table 2.2 f: Interrelations between Core Capability and Business Model Canvas

Core Capabilities	Elements	Design Management
Advanced Production Technologies	Key Resources	Management of People, Process, and Technology
Quality Control Capabilities	Value Proposition	Management of Information Integration
Schedule Control Capabilities	Key Activities	Management of Information Production

The business model canvas (Sparviero, 2019) is the tool used by this research to find potential strategies for improving design companies' business model. From the structure of the canvas, the research has targeted three items in order to explore their relation between building design management and design business operation, which aims to discover if the role of design management can impact on these three targeted items. According to the research findings, key resources is linked with advanced production technologies, which is related to people, process, and technologies from design management; value proposition is linked with quality control capabilities, which is related to information integration from design management; key activities is linked with schedule control capabilities, which is related to information production from design management. The detailed relationship of the proposed connection is discussed in this section. On this basis, advanced Collaborative, Interactive and Modelling technologies impact the design practices (Table 2.2.g).

Table 2.2 g: Findings of Impact of Different AEC Technologies

Technologies	Roles	Impacts
Collaborative Technologies	To enable collaboration among different design disciplines	To enhance efficient data production
Interactive Technologies	To enable sufficient evaluation and assessment for project design	To enhance efficient data understandings
Modelling Technologies	To enable detail and accuracy of the information model	To enhance information qualities

In fact, the modern building design process is increasingly reliant on IT technologies, due to the complexities of buildings (Hu, 2012), and design companies need to adopt suitable tools for efficient design development (Glodon, 2020). However, according to personal observations in the design market, most design companies are still using traditional design tools, for example, 2D-based design software, geometry-based 3D modelling software, and social media-based data transmission. The arrival of BIM paradigm can contribute to increased business performance for SME AEC companies (Kapogiannis, 2013), but the implementation of BIM relies on IT deployment and mobilization according to ISO 19650 (2018). IT mobilization in design companies is not sufficiently advanced (Oh et al., 2015), while during IT deployment the design company does not have a clear BIM implementation strategy (Wang, 2019). Despite the procurement of High-Performance Computers (HPC), BIM software, and other equipment, the BIM environment cannot be deployed correctly. Since modern building design is a combination of multiple disciplines (Hu, 2012), IT plays an important role in the design development. Moreover, BIM is the IT solution to integrated building data for the collaboration and coordination process; thus, there is high demand for a suitable BIM environment through efficient IT deployment. Henceforth, the adoption of the above into design practices might increase teams' core capabilities, as presented by ProQuest (2007); other areas that may benefit include land, labour, and capital (Longenecker, 2003).

Within the context of China, there is a demand to improve productivity in the Chinese AEC market to satisfy China's rapid development (Zhang et al., 2019). According to the Deng Xiao-Ping Theory (1978), science and technology are the most important factors of production, with productivity relying heavily on advanced technological solutions. With advanced productivity, the output from input per unit can be increased. AEC sectors are weighted very high in the Chinese total GDP but, despite rapid development, the ratio of output to input is relatively low, according to statistics (Zhang et al., 2019), mainly due to inefficiency and waste (Fu et al., 2019). Therefore, design companies need to adopt new SMPs to create a competitive business model in terms of core capabilities. Improved core capabilities can help design businesses to increase the output to input ratio.

2.2.2 Business Model in Design Practice

The building design business operates to provide building and infrastructure design services (Imrie, 2011). Building design is a complicated process which requires the coordination of multiple disciplines (Knotten et al., 2015); hence, building design companies need to employee people from different professional areas. Building design companies in the Chinese AEC market are classified into different types, with each type requiring a qualification license to provide services according to the relevant building codes. According to "Construction Project Survey and Design Management Regulations" and "Construction Project Survey and Design Qualification Management Regulations", the design qualifications are classified into: Integrated Qualification, Industry Qualification, Discipline Qualification, and Specialized Qualification. Most building design companies satisfy an industry qualification, and this type of qualification is categorized as: Building, Municipal, Public Utilities, Water Conservancy, and Power. Each category is classified as Class A and Class B.

Design companies cannot exceed the scope of their qualification (Ministry of Housing and Urban Rural Development, 2005), which regulates the type and the size of building for which the company can provide the design service. To obtain and maintain each qualification, design companies need to hire sufficient qualified professionals and required design services. Therefore, the operation of a design business has very high cost; so, a successful business operation not only needs to provide a high-quality design service, but also to balance cost and revenue. Hence, there is a high demand for optimization of the business model of design companies to be competitive in the AEC market.

Building design businesses in the Chinese AEC market provide a comprehensive building design service, including architecture, structure, MEP, and HVAC, according to observations. Building design services rely heavily on the input of human capital (Knotten et al., 2015). Despite utilities (office bills), physical input (printing), facilities (equipment), and tools (software), the cost of human capital is the greater burden, according to personal business management experience in a design company. As most human capital are highly educated professionals, salaries are very high. Although there are no precise statistics for salaries in the building design market, according to a search of online job websites, most salaries of qualified structural engineers in the Chinese AEC market are around CNY 300,000 (GBP 34,300), and the salary of a qualified architect is around CNY 350,000 (GBP 40,000).

The average salary during practice (before obtaining a professional license) is around CNY 100,000 (GBP 11,400), according to job market observation. A design company needs to hire sufficient licensed engineers and architects to maintain the qualification. According to regulations, the Class A design qualification requires the hiring of a minimum of eight professionals (at least three qualified architects) in the architecture discipline, eight professionals (at least three qualified structural engineers) in the structure discipline, and at least 10 professional engineers in MEP and HVAC. In this way, the estimated annual cost to maintain Class A industry qualification in terms of human capital is CNY 4,000,000 (GBP 457,200). Since building design businesses cannot cut the cost of human capital, the way to enhance business performance is to increase productivity and reduce waste.

Any investment needs to be well planned and studied to minimize the consequences of potential risks (Chiambaretto et al., 2020). Endeavor into a new market or adoption of new technology is risky (Ye et al., 2018); there are many uncertainties regarding Return on Investment (ROI) (Jordão & Sousa, 2010) while, according to Chinese regulations scope of business needs to be considered. The service provided by a company cannot exceed the permitted scope; for example, a license is required for building design companies to conduct certain building designs. Upgrade of the building design business license requires extra investment on capital and human resources (Eynon, 2013). Therefore, marginal cost will be generated from business expansion (Academy of Human Resource, 2002).

Business operation of building design companies is highly dependent on the performance of building design practice and building design practice depends on the quality of its information coordination. According to risk management theories, risk cannot be avoided (Bell, 1995), but risk does need to be minimized (van Winsen et al., 2016). Adoption of new technology is considered as business expansion (Guo et al., 2020), and there are many uncertainties in adopting new Standards, Methods, and Procedures (SMPs) (Teece, 2010). Although personnel training may not require an extra business license or procurement, there are expenses during the adaptive phase (Spencer, 2013). Moreover, there is still a risk if new SMPs substantially increase the companies' core capacities (Simon et al., 2014). Therefore, prior to increasing core capabilities through improving core technology competence, a clear risk management needs to be studied by the business management team to evaluate potential business performance.

To optimize the business model for improving the building design business, this research explores the structure of the building design business operation and identifies that the product of the design company has a direct impact on its business performance because the failure of the design production will cause no payment plus penalty fee. Other aspects are also important but make little difference in making improvement exceptional. Thus, this research argues for improving the production aspect to optimize the design companies' business model and improvement in the production process.

Products of the Business Model Canvas include Key Activities and Value Propositions. This research proposes that the Key Resource improves the Key Activities, and the Key Activities can increase the Value Proposition in building design business operation. In Chapters 4 and 5, this research validates those features and characteristics of LOD 350 that can increase design information coordination and subsequently improve design management. This part of the research discusses the potential impact of LOD 350 on each element of the Business Model Canvas since LOD 350 aims to provide "*the information about an element precisely and outlines an element's relation and connection with other components* (BIMforum, 2013)."

Key activities of the design business mainly focus on the design production process, which consists of each stage of the building design. The key activities rely on how the design team delivers their product, and product delivery is assessed through two criteria: quality of design and efficiency of design. Both the quality and the efficiency of building design delivery can be increased through improved design management. This research proposes the following strategies to validate the impact of LOD 350 on key activities:

- Improvement of the quality of delivered design documents subsequently leads to impact on key activities. The quality of design documents can be improved through coordinated design integration. The integration and coordination process of design documents is positively impacted by the adoption of the LOD 350 level of BIM model during design development.

- Improvement of the efficiencies of delivered design documents subsequently leads to impact on key activities. The efficiencies of the design delivering process is dependent on evaluation and assessment. The evaluation and assessment processes are positively impacted by efficient visualization solutions. The efficiencies of visualization depend on the model detail level and spatial coordination. LOD 350 has been validated as positively impacting the model detail level and spatial coordination.

Key resources of design business mainly focus on the technical solutions for satisfying different demands. These technical solutions rely on the sufficient and efficient allocation of relevant resources. Resources are largely the development strategies of the building design process, which mainly consist of human capital and IT facilities. Improved management of human capital can enable the design team to reduce production time, while improved management in IT adoptions will enable the design team to increase productivity by using the strength of each design tool and platform. Both human capital capabilities and IT mobilization can be increased through improved design management. This research has proposed the following strategies to validate the impact of LOD 350 on key resources:

- ➢ The improvement of the design team's capabilities can subsequently impact key resource allocation. The capabilities of the design team can be improved through increased IT mobilization. The success of IT mobilization depends on clear implementation of goals and strategies. A clear implementation strategy relies on the demanded information requirements such as functional and spatial demands. LOD 350 has been validated as substantially impacting on the response of information requirements during design production. Hence, the interrelation between LOD 350 and key resources has been established.

The value proposition of the design business mainly focuses on the awareness of the design results, which is aimed at enabling clients to understand the added value from the design progress and design delivery. The value proposition also benefits the design team by allowing maximum utilization of BIM solutions to help with building project development. Specifically, this aspect highlights added value through the improved design management process. The clients and stakeholders can increase their understanding of project design and foresee the future perspectives of the project through improved communication and the immersive visualized environment, while design team efficiency is improved in the design delivery process. Both communication and the immersive visualized environment can be increased through improved design management. The research proposes the following strategies to validate the impact of LOD 350 on value proposition:

- Improved communication can enable the client to increase the understanding of their project in a holistic way, which can subsequently lead to increased awareness of the added value of the project. The improvement in communication during the design development depends on the immersive visualized environment. The immersive visualized environment depends on the quality and the detail of the produced design information. The quality and detail of the produced design information depends on information management. LOD 350 is validated as a suitable reference during the modelling process. Hence, the interrelation between LOD 350 and value proposition has been established.

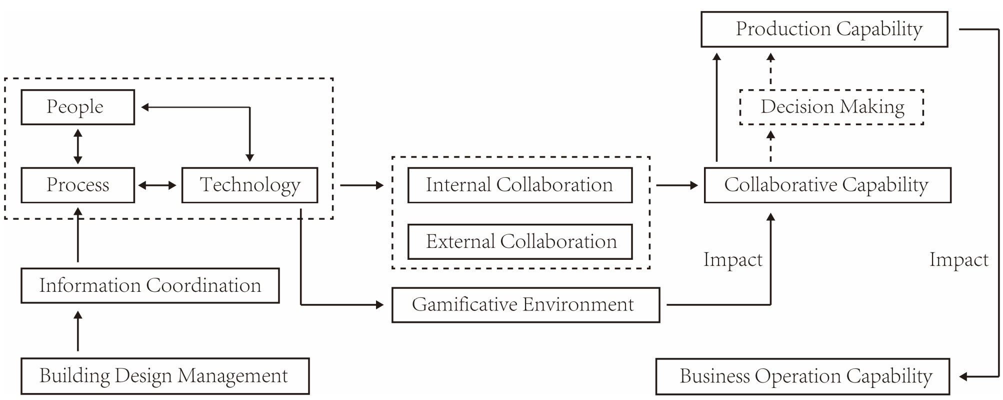


Figure 2.2 b: Proposition for Improving Building Design Business Operation

(Figure 2.2.b) shows strategical development to improve the capability of business operations. The integration among people, process, and technology increases the collaboration capability. Hence, production capability can be increased for enhancing business operation capability. Therefore, building design companies need to update new technologies during the design process to increase their core capacities. From this perspective, the design business needs to maintain their advance in production technologies (Norman, 2017). BIM, which relies on efficient IT deployment (Arayici et al., 2011b), is increasingly adopted in many AEC industries, and many design companies have teams to integrate BIM with design development, according to China BIM annual report (Fu et al., 2019).

However, many design companies do not realize the importance of a BIM Execution Plan (Shillcock & Cao, 2019b), and consequently implement BIM in an unmanaged way (Cao et al., 2015). In many scenarios, BIM is implemented based on old facilities, not managed in a collaborative environment. This leads to a “fake-BIM” mode, which causes additional workload but little output. Traditional IT deployment in design companies is not in a collaborative environment, and data and information are not co-ordinated (Czmoch & Pękala, 2014). To improve teams’ core capabilities, design companies need to deploy IT according to BIM requirements (Borrmann, 2018), while IT deployments need to comply with BEP due to different project information requirements (ISO, 2018b). IT deployment in BIM implementation needs to be in a collaborative environment (Kapogiannis & Sherratt, 2017), suitable for meeting design workflows (Gholizadeh et al., 2018). Therefore, based on the findings in the literature review, this study proposes that design companies deploy IT systems in a collaborative way to satisfy BIM implementation. This research also proposes that a collaborative culture-based IT deployment will cause better data coordination, which subsequently leads to a better design evaluation process and quality control.

Multiple issues have been identified in design business operations, and three solutions are proposed, which are: improvement of design workflow through integrating a collaborative culture and information management; establishing an information-based gamificative design and review environment; and deploying an IT system based on collaborative culture. However, the real implementation of the proposed solution has limitations, and it is not clear how exactly these solutions will impact design business operation.

It is difficult to integrate a collaborative culture and information management into a design workflow when architects and engineers in design companies are accustomed to working in traditional methods (Wang, 2019). According to literature reviews, many reports and case studies have identified that the cost of training new technologies is high, and during the period of training, there is no substantial design output (Glodon, 2020). Therefore, investment in technology has little profit return in the short term (Longenecker, 2003). The successful development of a digital environment can contribute to the business model (Guo et al., 2020). The business model created by design companies requires long term development. There is a gap in technology adoption strategies and, according to the literature review, there is a lack of specific solutions to conduct an efficient BIM workflow for design companies to improve core capabilities. Therefore, a BIM soft-landing solution for design companies needs to be found to fully adopt BIM through collaborative information management in design development.

To establish a gamificative environment efficient IT deployment is needed, which may require additional training. It is unclear what level of detail is required for the information model in a gamificative environment designed to improve performance in design management. BIM models provide a platform for data coordination and information visualization (Eastman et al., 2011). Trimble, in collaboration with Microsoft, have developed a CDE that allows an image visualised in a VR and a MR environment to be communicated collaboratively over distance and shared with team members remotely (See Table 2.2.h).

Table 2.2 h: Trimble Connect and Microsoft HoloLnes2

 MS HoloLens 2 Re-developed by Trimble, with integrated safety helmet for usage in construction site.	 Test at BIM Lab in the University of Nottingham Ningbo China - Ningbo Lishe Airport Project. Intervention study 3 in Chapter 4, Section 4.2.3 (**pp. 293 -310**).

However, since BIM Modelling software does often not provide gamification functions, according to market observation, additional efforts need to be made to find the appropriate gamificative engines to develop the desired environment. According to the definition of gamification, it is not quite clear what exact functions need to be included in this environment. Since game development requires a lot of effort, gamification for building design cannot reach the level of a real game. There is a gap in the development of a gamification environment, and design teams need to find a balanced level (for both details and costs) so as to contribute to design management.

How IT deployment in BIM implementation can impact design management needs to be further validated, since it is not clear how each relevant tool can impact the proposed solutions, such as the gamificative visualized environment, collaborative design and evaluation environment, and information management systems. According to the literature review, the findings argue that IT systems needs to be deployed in a way that can create a collaborative design and assessment environment. However, the level of impact of IT mobilization on design efficiencies has not been validated, according to the literature review. Whether collaborative technologies in BIM implementation can positively impact design development and how these technologies can impact the design business operation is not being studied. There is a gap between collaborative technologies and design development, and design companies need to find an impact strategy for improving design efficiencies by using suitable IT deployment.

Information coordination is impacted by communication, collaboration, and design details. Communication is associated with IT mobilization and information integration, design detail is associated with IT mobilization and information production, while collaboration is associated with all these aspects. Therefore, the efficient allocation of resources and the efficient conduct of activities contributes to information coordination for impacting the quality of design delivery (Figure 2.2.c). Moreover, due to communication, collaboration and design detail are impacted by the combination of ISO 19650, LOD 350, and Gamification. Hence, the quality of building design delivery can be impacted through the integration of these features and perspectives.

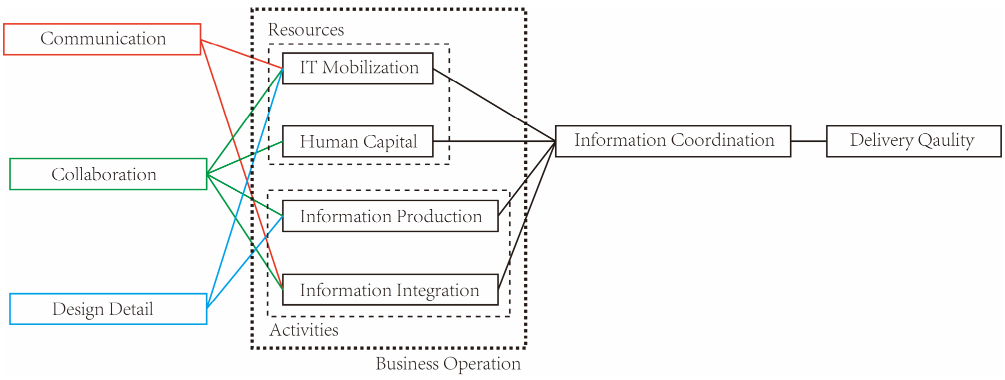


Figure 2.2 c: Interrelation Between Building Design and Business Operation

Gaps have been identified in building design business operation in terms of lacking specific solutions and implementation plans for BIM adoption. There are many theories on how to improve the core capabilities of design companies and, although it is not clear how to efficiently implement them into a real project, there is a connection between each gap, according to the findings (Yang, 2015). The way that IT is deployed can impact the establishment of a gamificative environment, and an efficient gamificative environment to increase technology adoption, which will subsequently lead to an improved coordinated design workflow to enhance building design business operation.

Those significant issues that cause inefficient design coordination are, insufficient communication between clients, insufficient collaboration among the design team, and insufficient data integration, which need to be solved to improve the building design management process. Findings show that the productivity of design companies is relatively low, and there is a need to adopt new SMPs to increase core capabilities in building design business operation. Issues in design modification, design assessment, and IT deployments in the design business highlight that building design companies are not operating according to modern design workflow, and most design development processes are still based on experience-based traditional methods.

Building design business operation needs to focus on resources and activities during the project development. According to the findings, IT mobilization and human capital are categorized as resources, while information production and information coordination are categorized as activities. Communication, collaboration, and detail design impacts these four aspects accordingly (Table 2.2.i). The findings show that collaboration is interrelated with all the aspects in resources and activities. Therefore, the building design business operation is highly impacted by the efficiencies of the collaboration process.

Table 2.2 i: Findings of Factors that Impact on Business Operation

	IT Mobilization	Human Capital	Information Production	Information Coordination
	Resource		Activities	
Communication	√			√
Collaboration	√	√	√	√
Design Details	√		√	

Business operation depends on teams' core capabilities, including both teams' production capabilities and research capabilities. The major activity of building design companies is design production for construction. Therefore, core production capabilities are the key aspect of core capability. As identified, the most important core production capabilities of building design business need to focus on quality control and schedule control. Therefore, with improved building design management and key activities, the core production capabilities will improve (Figure 2.2.d). The improved teams' core production capabilities impact the quality of building design delivery, which can subsequently lead to enhanced business operation performance.

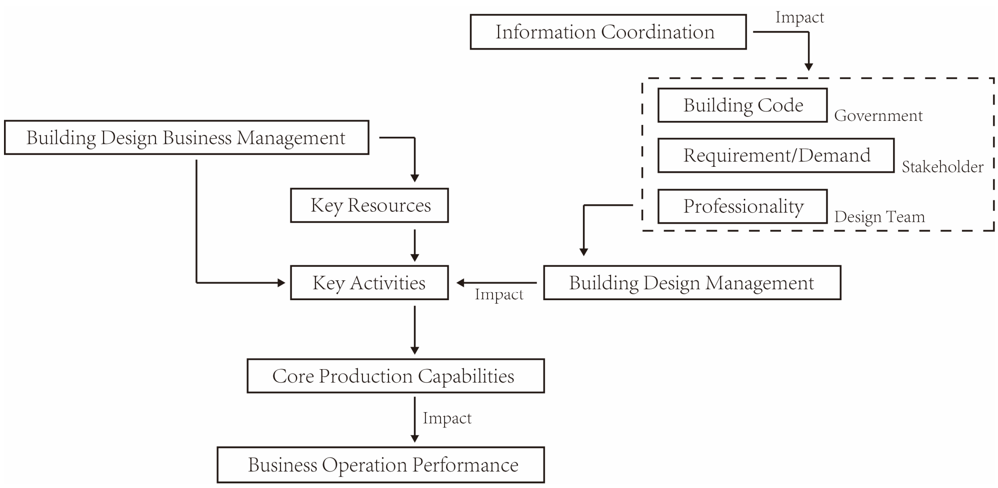


Figure 2.2 d: Summary of the Impact of Information Coordination on Business Operation

The findings from the literature review show that the business operation of building design companies depends on the design production capabilities, and the design production capabilities depend on the efficiency of information coordination. (Figure 2.2.d) shows the impact of information coordination on business operation performance. There are three aspects that need to be taken into consideration for information coordination: building codes from the government side, requirements from the stakeholder side, and professionality from the design team side. Together, they contribute to building design management. The literature review has identified that design business operation needs to consider key resources and key activities to improve its performance. Key resources include IT mobilization and Human Capital, and Key Activities include Information Production and Information Integration. Key resources contribute to Key Activities, and Key Activities are impacted by building design management. Therefore, it is important to better understand the design document development process, management, visualization, and visualization in design practices. This is presented clearly in the next section.

2.3 Design Document Development Process, Management, Visualization, and Visualization in Practice

Information management in building design is inefficient despite the existence of theories, standards, and technologies. Most precedent studies focus on single technical or theoretical implementations, yet this cannot satisfy the complexity of building design information coordination. There are three areas of concern: Data Inconsistency, Data Insufficiency, and Data Miscellaneous, and gaps are related to the way to develop data, the way to integrate data, and the way to visualize data.

Section 2.3.1 to Section 2.3.5 discuss the importance of design management and summarise its role in building design projects. Design information coordination is heavily reliant on an efficient design management process and improved production capability requires improved information coordination, which results in enhanced building design business operation. Since the latter is the aim of this research, design management is an important part of the process. This section categorizes building design production into four stages:

- ✧ The importance of managing the design during the information development stage.
- ✧ The importance of managing the design during the information transmission and integration.
- ✧ The importance of managing the design during the information visualization.
- ✧ The importance of managing the design during the information delivery.

2.3.1 Design Document Information Development Process

The building project comes with relevant demands and requirements from the client's side, since they are the source of investment (Best, 2006). These requirements usually involve a variety of different aspects due to the complex nature of the building, for example, functional requirement, spatial requirement, appearance preference, and budget limitations (Imrie, 2011). This section discusses the importance of design management for satisfying the above project requirements.

Building projects come with clear purposes (Eynon, 2013). The design stage of building development aims to satisfy those demands for usages and functions of the building project (Pikas et al., 2018). The design team needs to clearly understand how the building will be used and consider those demands (Rounce, 1998). Design management needs to ensure the design team can meet the relevant functional requirements during planning and design development (Taylor, 2000). Sufficient design management with advanced SMPs will enable an efficient design process, which can subsequently lead to successful design delivery (Ingram, 2019).

Building projects come with certain budgets (Rounce, 1998), so the design stage needs to help the developer to limit the construction cost within the relevant budget, since the cost of construction is calculated based on the design documents (Trani et al., 2015). From each phase of the design development, the project developer can understand the cost estimation (Schematic Design), cost estimation amendments (Technical Design), and cost final budget (Construction Documents). According to the domestic regulations of the Chinese AEC market, construction documents are the only reference for construction budgets. Therefore, design management needs to ensure that the design team can produce the required accurate information during construction document development. Hence, sufficient management through adopting LOD 350 will contribute to managing the detail design for quantification.

Clients of building projects require a particular aesthetic of building façade and elevations (Hu, 2012). The design stage needs to meet the appearance requirements, such as volume, shape and height, as well as the functional and budget aspects (Knotten et al., 2017). The design management needs to ensure that the design team can balance the requirements to meet the relevant criteria (Rounce, 1998), and there is often an imbalance between function and appearance due to poor management (Pikas et al., 2018). Hence, the adoption of advanced design management strategies and technologies can avoid this problem.

The next stage during the design process is to produce the correct content and information based on the relevant design requirements (Knotten et al., 2015). These include the design and modelling process (Imrie, 2011), as will be discussed and validated in the Chapter 4 intervention studies (Pikas et al., 2018). For more detail, this section explains why management is important during the information production process to highlight its impact at later stages (Knotten et al., 2017). It focuses on requirements from the project itself, from building codes, and from construction techniques to discuss management during information design and modelling.

Building designs need to satisfy project requirements, for example, it needs to meet relevant requirements such as function, budget, and appearance. Information production during design development needs to satisfy these requirements and to fully produce detailed information for construction development (Sacks et al., 2009). Building design is a complex process with a lot of information and details from many different disciplines, so design management needs to ensure that the information produced meets the design requirements (Singh et al., 2011). Also, to avoid the information being scattered, it must be well coordinated. Hence, improved design management can increase information production quality.

Building designs must meet building codes and regulations (Imrie, 2011). There are many codes and standards that regulate building project development, and design documents need to pass relevant inspections before handover to construction development. At each phase of design, design management must ensure that information produced by the design team meets the required building codes in order to avoid rejection (Tauriainen et al., 2016) as, if this occurs, the required design modification will cause project delay. These issues can be avoided through the improvement of design management.

Building designs need to produce technical details for construction (Knotten et al., 2015). Construction development is based on the delivered design documents, and the design documents need to include details for fabrication and installation, according to the domestic regulations of the Chinese AEC market. For some complex projects, the construction team might need more information for detailed construction. If anything is unclear in the design documents, meetings will be requested with the design team for discussing the relevant issues and hence, delay will be caused. Thus, it can be concluded that the design documents will directly impact the construction development, which will also affect the design development. Design management needs to ensure that the design team are producing sufficient details for construction in order to avoid any misunderstandings (Knotten et al., 2017). Effective design management can help the design team to reduce this potential extra workload during construction development.

2.3.2 Design Document Information Transmission and Integration

Due to the various design disciplines involved in building project development, data integration and coordination are very important during the collaboration process once each discipline has submitted their design documents (Porter et al., 2015). Furthermore, each stage of the design outcomes needs to be reviewed by the client team for ensuring the design is meeting project requirements (Hu, 2012). The transmission of data between the design team and client team is also considered as important for design management (Emmitt, 2013). Also, data needs to be shared with a third-part specialized design service if the design team needs additional technical support (Eynon, 2013). The role of the design management team is to guarantee that the data are transferred, and to ensure the correct data are received (Knotten et al., 2017).

Building design requires collaboration of multiple disciplines and professionals (Figure 2.3.a). There are five major disciplines during building design development, and the building design needs the support from third-part professionals regarding technical issues such as the energy assessment report and high-quality renderings. Therefore, the efficiency of information and data transmission between these disciplines will affect the qualities of the design coordination. The role of design management is to ensure sufficient coordination between each discipline, and to ensure that integrated design documents meet functional purposes (Taylor, 2000).

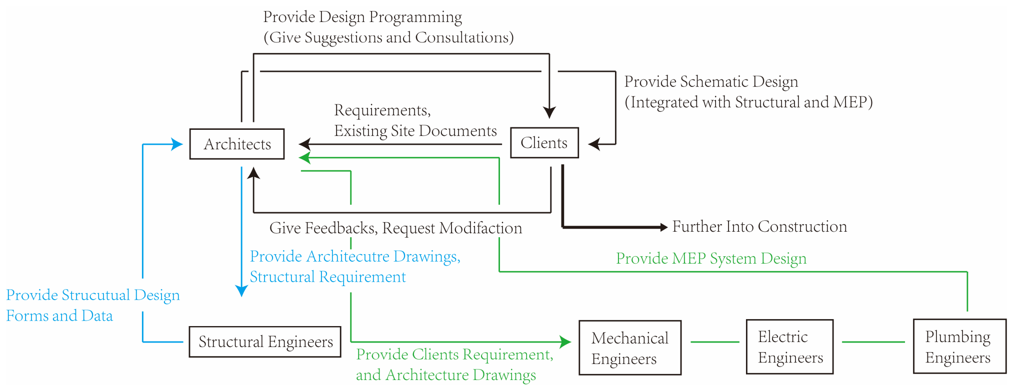


Figure 2.3 a: Collaboration Between Different Design Disciplines

Building design requires communication with clients and stakeholders (Hattab & Hamzeh, 2017). Project demand and regulations are from clients and stakeholders (Figure 2.3.a); so, the design team needs to satisfy those requirements, based on complying with relevant building codes (Imrie, 2011). The communication process between the design team and client team needs to ensure the design documents are understood for improving the decision-making process (Juszczyk et al., 2016). Design management during project development needs to ensure sufficient communication with clients to guarantee that the design progress is on the right track (Liu et al., 2017).

According to observations from the AEC industry, building design demands the participation of third-party technical services and support. During the design process, it is quite common to hire third party companies to provide services and technical support (e.g., rendering, animation, energy simulation, etc.). During that time, the design team needs to establish clear communication to express the relevant requirements and demands regarding the project. The efficiencies of communication determine the quality of collaboration (Cooper, 2019); therefore, the role of design management is to ensure the building design is correctly delivered (Eynon, 2013). Also, during the collaboration process, the design management team needs to ensure that progress is on schedule for meeting the overall design schedule (Elmualim & Gilder, 2014).

Building design must collaborate between different design and engineering tools because a single tool cannot satisfy the entire project. Therefore, data exchange during design production is required (Figure 2.3.b). There are two major categories of data exchange during BIM implementation: OpenBIM and Closed BIM. OpenBIM allows data to be exchanged between every production tool via a certain data format, while Closed BIM can only exchange the data within the tools from a single software vendor. Since building design requires collaboration between multiple discipline and other service parties, a single software vendor cannot provide all the required tools. Therefore, OpenBIM has advantages and is a future trend. However, its level of sophistication is not sufficient to completely support building project development.

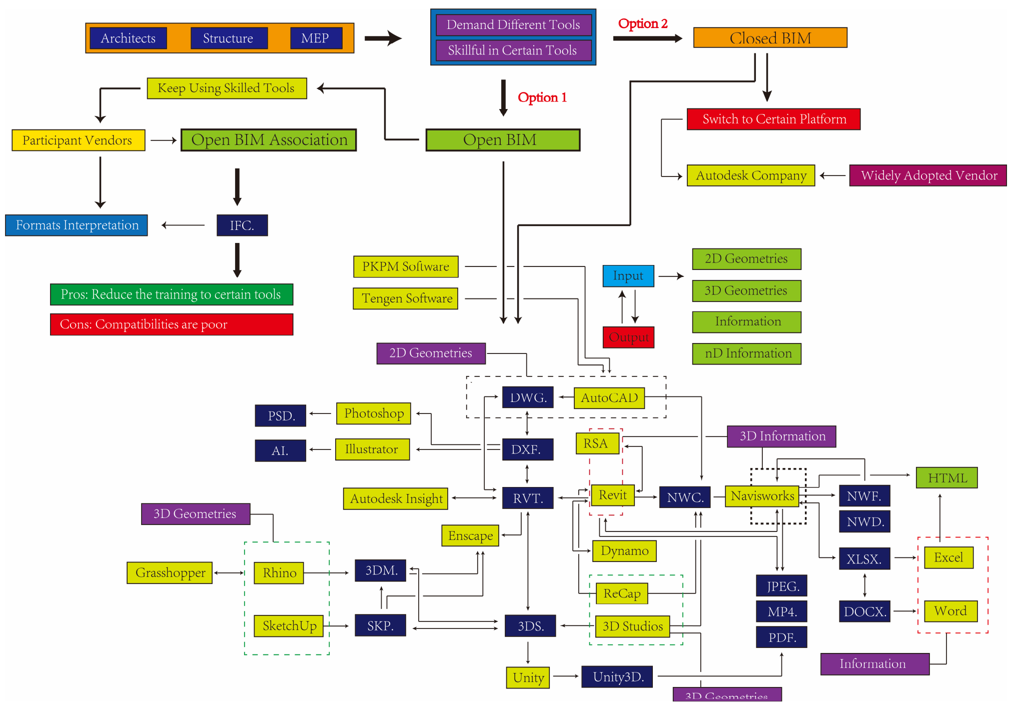


Figure 2.3 b: Findings of Data Exchange in Building Design

The purpose of data transmission is for the preparation of the later integration and development (Ingram, 2019), and the purpose of design integration is to ensure that the entire design meets the relevant requirements, such as functional, spatial, and technical aspects (Hattab & Hamzeh, 2016). This section discusses why sufficient design management can increase the design coordination, and how the proposed management solution can potentially improve the data integration process. The validated scheme regarding adoption of LOD 350 in BIM model development highlights the significance of design management during the data coordination process.

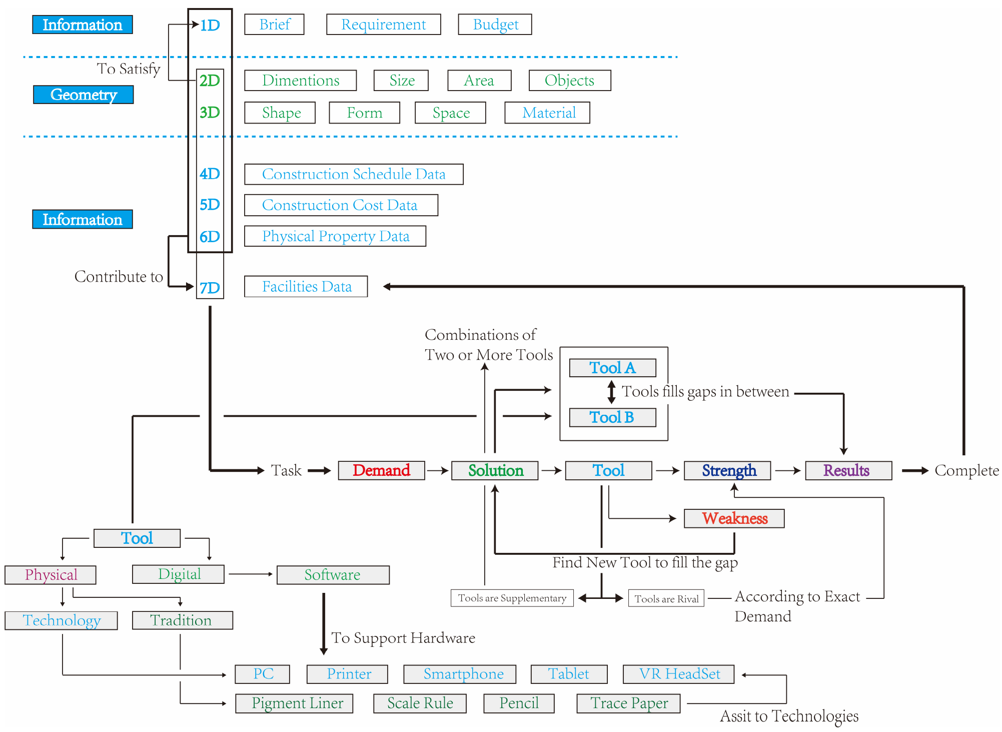


Figure 2.3 c: Different Dimensions of Information Coordination

The data integration process involves coordination between each stage of the requirements and involves collaboration between different production tools (Figure 2.3.c). The building information model contains both graphical and non-graphical information, which is developed from 1D to nD. According to findings from the literature review, 1D is merely the non-graphical design information itself. 2D and 3D contain graphical information and non-graphical information, while the remaining dimension includes different types of non-graphical information. With the development of each dimension, coordination between software and hardware is required for ensuring the quality of design delivery. Design data are integrated from each stage to guarantee that the correct and appropriate information is produced.

Design development involves multiple stages, and the different dimensions of the information need to be integrated and coordinated for satisfying the requirements (Figure 2.3.d). Each dimension of the design production is linked with the following stages, according to the findings, which can consequently impact quality of the final construction document delivery (Ghaffarianhoseini et al., 2019). During the programming, the building is categorized into functional, spatial, budget, and performance (Pikas et al., 2018). Functional and spatial information is produced from 1D to 3D, while budget and performance information are developed into 5D and higher. The production and integration of each information dimension uses tools and data exchange (Figure 2.3.d).

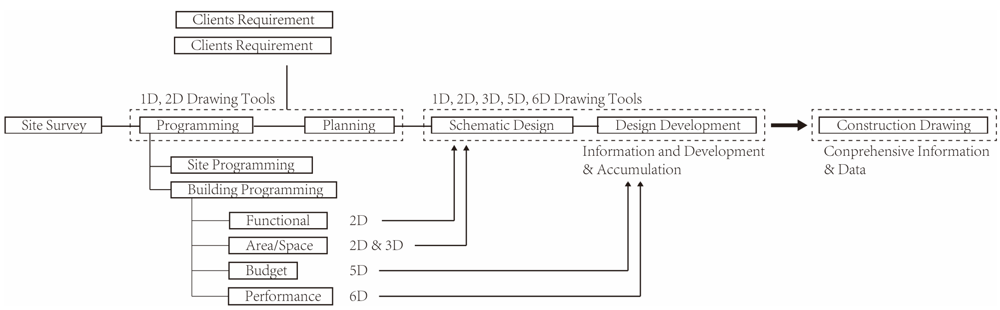


Figure 2.3 d: Development of Building Project

The production of each spatialized design needs to be coordinated for functional purposes (Fagan, 2019). The construction project is a very complex process so a single design company cannot meet all technical satisfactions during the engineering development. Thereafter, support from third part companies is required for collaboration in many specialized designs (e.g., glass curtain wall, intelligent facilities, etc.). During the collaboration process, accurate data transmission is required for design accuracy. The role of design management is to ensure the data from the design team is accurately delivered to third party technical companies, the data from third party companies meet the requirements of the project, and that these data can be integrated with the existing design (Knotten et al., 2017).

The production from each design discipline needs to be integrated for spatial clearance (Svalestuen et al., 2018). There are multiple disciplines during the design progress, and the design outcome from each discipline has spatial occupancies. Therefore, during the integration process, there are likely to be spatial clashes because of the geometric size of each building component. The role of design management is to ensure that clashes can be detected and coordinated for providing a free-clash design document (Angelo, 2013). During the integration and coordination process, the transmission of data from central documents to each discipline needs to be holistically managed for ensuring sufficient coordination (Uusitalo et al., 2019).

The production of each building component must be interrelated for the asset system (Ingram, 2019). The BIM model is for establishing the required Asset Information System, and the efficiency of the asset system is based on the Asset Information Modelling (AIM). ISO 19650 regulates that the AIM needs to be in accordance with the Asset Information Requirement and is a much-specialized model of Project Information Modelling (PIM). During the model development, each building component must meet the requirement from the asset management system for the connection between model and system (Motawa & Almarshad, 2013). The role of design management is to ensure each of the building components is designed and modelled with the required specification for functional purposes (Pikas et al., 2018).

2.3.3 Design Document Visualisation

A fully optimized BIM model during the design phase helps to avoid many potential problems at the construction phase. The visualization of graphical data can contribute to understanding of project design and improve the design coordination process, while the visualization of non-graphical data can enhance project simulation performance. Efficient data visualization of the building project requires sufficient and effective design management for enabling the project to develop in a much clearer way.

Coordination of the integrated data requires an efficient method (Kang & Choi, 2015). This research has found that the visualization of building data will improve the information coordination process (Shi et al., 2016). Not only can the graphical data be visualized to increase understanding of the design process and increase spatial coordination development, but they can also be visualized to support the simulation process (Nicał & Wodyński, 2016). This section discusses in detail the reason for arguing why design management can improve project design performance.

The visualization of graphical information can improve understanding of the building project (Lin et al., 2018). This research has validated that increased detail in graphical information can increase project understanding through study of case scenarios. The symbol-based 2D design outcome is far too abstract to be understood by non-professional project participants for decision-making (Holly et al., 2021). The research has found that the immersive interactive visualized design environment can improve the coordination and collaboration process. The visualization mostly depends on the graphical information of the project model (Zaker & Coloma, 2018); therefore, the role of design management is to ensure all the geometric details are developed by the design team to enable the efficient visualization process. Furthermore, the design management team needs to properly manage the relevant visualization technologies for maximum understanding of the project (Smith, 2014b).

Visualization of design information can increase the coordination of the building project (Succar et al., 2013). This research has proved that visualized design information can positively impact the spatial coordination process through the study of case scenarios. The details of geometric information not only enable the coordination of spatial design, but also contribute to functional assessment of the relevant activities (Koskela et al., 2018). Design management can increase the integration of information for an improved visualization process since there is normally a massive amount of design information produced during design development (Elmualim & Gilder, 2014). Choice of the most appropriate information can help the coordination process, and therefore shows the role of design management during the visualization process.

The simulation of non-graphical information can enhance interrelations of the building project (Uusitalo et al., 2018). An information model contains graphical and non-graphical information. Graphical information can contribute to the visualization process, while non-graphical information can impact project management from the medium to long term (Holzer, 2016). One of the most important ways that non-graphical information is used is for asset management purposes. A database built in a BIM model can help the project team to extract the required information to conduct the relevant facility management (Fraser et al., 2013). The role of non-graphical information at the design stage is to improve the quantification survey and can also improve the relevant engineering simulations (Shi et al., 2016). Efficient design management can improve the information modelling process from the design development, which will enable the correct information accumulation progress (Latiffi et al., 2015).

2.3.4 Design Document Information Management and Information Development

Building design is a complex and comprehensive technical process nowadays, which relies on the coordination of multiple disciplines (Emmitt, 2013). Building design usually consists of five main disciplines in most projects: architecture, structure, plumbing, electricity and mechanical. Some complex buildings require more specialized design, such as glass curtain walls, surveillance, intelligence design, etc. Many technologies and skills are required to satisfy project demand (Eynon, 2013). Knowledge about buildings and software manipulation techniques are the two most important aspects of design development (Knotten et al., 2017). Designers and Engineers need to know what to do and how to do it during the design process to successfully delivery the correct contents (Best, 2006). Also, the design output needs to comply with relevant regulations according to national and local building codes. Therefore, building design projects need to follow people, process, and technologies.

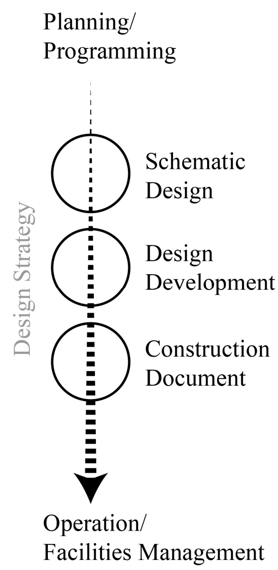


Figure 2.3 e: Stages of a Building Project

Building design consists of multiple stages, see (Figure 2.3.e). There are three stages of design according to the RIBA Plan of work 2020, which are: Concept Design, Spatial Coordination and Technical Design. The Ministry of Urban and Ural Planning of China announced the <Regulation of Building Engineering Design Documents Depth> in 2016, which classifies building design into four stages: Concept Design, Preliminary Design, Construction Documents Design and Specialized Design. The American Institute of Architect (AIA) classifies the design phase into Schematic Design, Design Development, and Construction Documents. Despite the slight difference between each country, the overall schemes are the same. Building design begins with a concept to figure appearance and functions, followed by design enhancement, and finishing with a detailed construction illustration (Imrie, 2011).

During each stage, clear tasks and information need to be produced, and this produced information needs to be consistently and effectively transferred onto the next stage (Czmoch & Pękala, 2014). Design data and information between each discipline requires efficient coordination during each phase to meet the expected output quality (Rounce, 1998). Thus, information coordination and management are critical during building design. However, if design drawings need to be reviewed, checked, and approved by the requirement of ISO 19650, then better information coordination during the design development is needed.

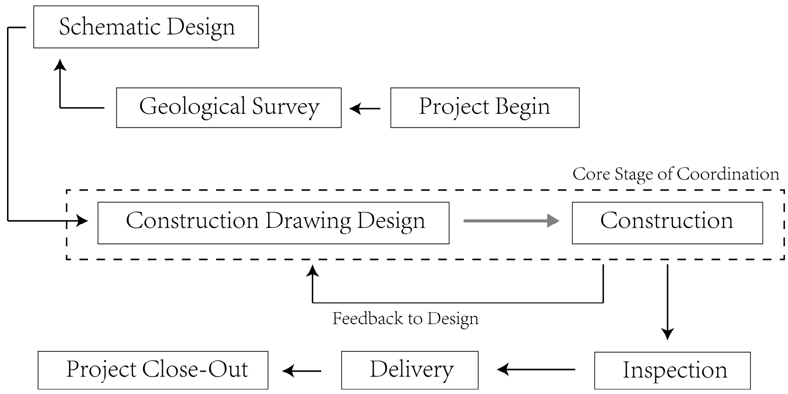


Figure 2.3 f: Integration of Design Data Production during Each Stage (Yang et al., 2020)

Building design is a very complex process consisting of multiple stages (Figure 2.3.f). Following the survey and design stages, the building needs to be constructed ready for operation. Information produced during the design phase will be modelled to help stakeholders gain a better understanding of the status of the project though the adoption of various visualization technologies. On this basis, during stakeholder meetings, information needs to be exchanged to decide whether the design drawings require further input, with the challenge being clear information so as not to cause misunderstandings. Moreover, better coordination will help the design team and other stakeholders to eliminate certain risks, not only via modelling but also through continuous feedback.

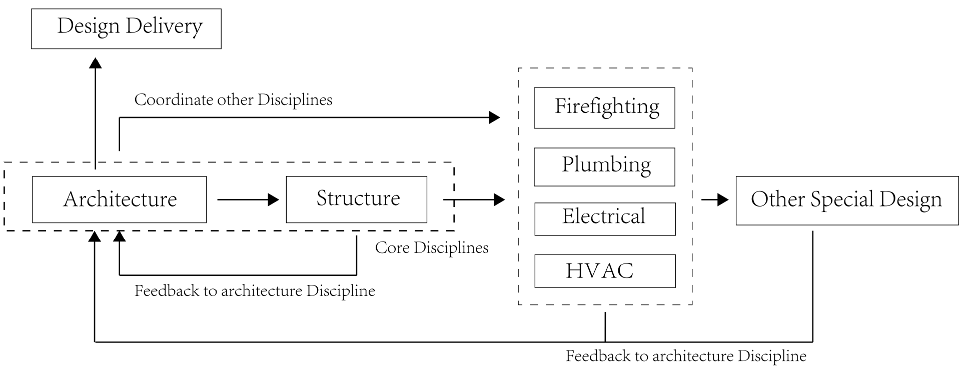


Figure 2.3 g: Design Coordination between Different Disciplines (Yang et al., 2020)

Multiple participants are involved during the building design phase, see (Figure 2.3.g); therefore, discussions and assessments are always required during design development. Poor information coordination will cause confusion of project understanding and result in project failure (Deutsch, 2011). Building design requires efficient coordination and collaboration within the design team, as well as effective communication with clients and stakeholders (Alharbi et al., 2015). Successful management of the design process can lead to high quality delivery, save more time and increase client satisfaction (Ingram, 2019). The most important thing during the management process is to enable people to fully engage with the design development (Singh et al., 2011). The design output is dependent on the degree of involvement from each participant (Emmitt, 2013). According to Kapogiannis (2013), the collaborative environment will enable better project performance. Therefore, to successfully complete the design project, building design needs an efficient way to have clear information, coordinated in such a way that stakeholders have access from anywhere at any time. That happens because collaboration aims to unite people (Kapogiannis, 2013) and allows sharing of files and all relevant design documents for review, check, and approval according to ISO19650.

Building design quality depends on multiple factors, for example, the appearance (Best, 2006); the outdoor and indoor functions satisfying usage demand (Eynon, 2013); satisfaction during post-occupancy evaluation by users (Nicał & Wodyński, 2016); clear instruction to construction process (Bagnasco et al., 2015); and management in budget controls during the design process (Smith, 2016). To satisfy all these criteria, during the design phase a building project requires excellent organization of the relevant information (Koskela et al., 2018).

The spatial coordination among different disciplines is one of the most important factors to impact design qualities (Uusitalo et al., 2019). Poor spatial coordination will cause problems during the construction phase and even during the maintenance phase (Peckienė & Ustinovičius, 2017). (Figure 2.3.h) shows the relation between different building elements. Clashes happen frequently among different disciplines, especially during MEP installation (Knight et al., 2010). Badly coordinated space will impact on clear height, which subsequently will affect functional usage (V. Singh et al., 2011). The appropriate strategies during spatial coordination will enable design teams to increase design efficiencies (Merschbrock & Munkvold, 2015). Therefore, it is important to choose the most suitable standard methods and processes (SMP) to conduct spatial coordination. (Figure 2.3.h) shows the interrelation between each building element.

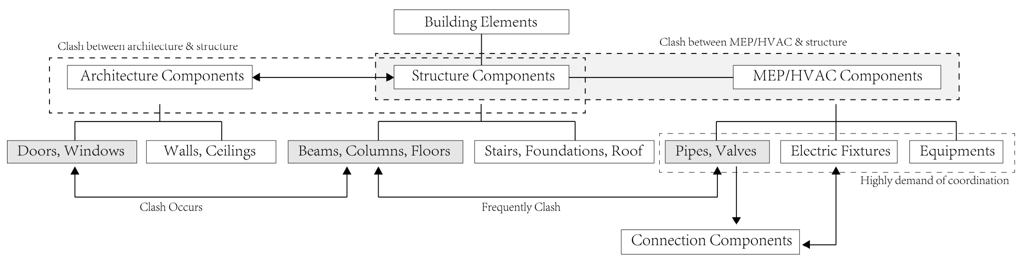


Figure 2.3 h: Coordination Between Different Building Elements (Yang et al., 2020)

Design visualization during the development process is quite effective because it can help design teams better assess potential problems (Tjell & Bosch-Sijtsema, 2015). 3D-based design development will allow different participants involvement in a project, including clients and stakeholders, to directly evaluate the design (Bresciani, 2019). Different data and information integrated into a 3D-based model will enable the design team to collaborate in a more visualized way (Juszczyk et al., 2016). A clear vision of data can improve the performance of design development (Comi et al., 2019), while collaborative technologies can increase the collaborative culture, which will lead to improved project performance (Kapogiannis, 2013). Thus, implementation of visualized technologies during the design phase will subsequently enhance the efficiencies of design development.

Kapogiannis et al. (2021) validated that a collaborative environment increases proactive behaviour during project development, which highlights the importance of collaborative communication. Much of the communication during the design process lacks in-depth information, which will cause misunderstandings (Norouzi et al., 2015). Clear information delivery requires correct data at an appropriate time, that can be retrieved at any time in any place (Lauff et al., 2020). The security of the information delivery and storage should be considered during the project development as the building may contain sensitive, classified data (BSI, 2015). Therefore, successful communication during the design phase will help to improve design management.

Lean project management, introduced by Koskela (1992) enables AEC industries to conduct better management, thus increasing project performance. Lean management encourages proactive behaviour during production (Koskela et al., 2019). The more the design team engages, the higher expected project performance (Sacks et al., 2017). According to literature reviews, effective design coordination depends on involvement among team members (Elmualim & Gilder, 2014). There are three classifications of production behaviour: inactive, reactive, and proactive (Kapogiannis & Sherratt, 2017). Each level leads to different design performance. Kapogiannis (2013) tested whether proactive behaviour can increase project KPI. Therefore, introduction of lean management into building design development can potentially increase the performance of design management.

3D models in building design projects need to contain sufficient detail to support the development of the design process. The model in a BIM-driven project needs to contain both graphical and non-graphical information, according to BIM criteria. Both graphical and non-graphical information in a 3D model needs to be developed by meeting the demand for satisfying the relevant requirement. The specification of Level of Development (LOD) offers a great reference for producing the information for the development of a 3D model during BIM implementation. Each LOD is used in different design stages for meeting different purposes. Adoption of LOD specifications can ensure the suitable amount of workload at each stage of modelling and that the transition from each modelling stage can be processed in a correct way. Therefore, LOD has the potential to impact the coordination of design information during the modelling production process.

The arrival of ISO 19650-1/2 in 2018 offers clear reference to information management for effective implementation of BIM to enhance project performance. ISO 19650 highlights that everyone in the design team is an information manager, and everyone needs to be compliant with the Responsible, Accountable, Consulted, and Informed (RACI) matrix. Moreover, the information cascade introduced by ISO 19650 identifies the role of each team member in a hierarchy, enabling efficient information production, check, and delivery. A clear project schedule Master Information Delivery Plan (MIDP) consists of a multiple Task Information Delivery Plans (TIDPs) to enable better quality control according to ISO 19650. Organization Information Requirement (OIR), Project Information Requirement (PIR), and Exchange Information Requirement (EIR), introduced by ISO 19650, enable the design team to better understand demands from clients and stakeholders, developing relevant information and consequently satisfying project requirement. Hence, design management can be conducted in a more organized way.

BIM is an integrated solution for the management of building projects in AEC industries which is aimed at establishing an integrated environment for information development during the building life cycle (Eastman et al., 2011). AEC technologies are becoming increasingly sophisticated in assisting building design (Gokuc & Arditi, 2017). Adoption of these technologies can contribute not only to visualization but also to data interoperation (Lou et al., 2019). Emmitt (2013) argued that BIM as a collaboration method would enable the design team to use a single model for coordination purposes. There are three levels of BIM, according to BIM training given by the Building Research Establishment (BRE) in 2019: Building Information Model, Building Information Modelling, and Building Information Management (BRE, 2019). The overall aim of BIM implementation is to create Better Information Management. BIM is sometimes referred to as Business Information Management, due to its role in design business information coordination (Kapogiannis & Sherratt, 2017). Beyond the design phase, BIM is widely adopted during the construction and maintenance phases (Wanigarathna et al., 2019).

BIM can be used for a variety of purposes during the building design development (Arayici et al., 2011). One of the most significant aspects is that everything can be processed in a visualized way during design coordination (Eastman et al., 2011). The visualization tools include both software and hardware (Succar et al., 2013), which rely on an efficient BIM environment based on the building systems (Deutsch, 2011). BIM software is categorized into geometric modelling software, information development software, data analysis software, and file interchange tools (Jernigan, 2008). BIM hardware includes data collection devices, data transfer equipment, data storage terminals, and data processing units (Eastman et al., 2011). BIM is a collaborative implementation which relies on efficient coordination among people, process, and technologies (Holzer, 2016). Therefore, the successful BIM implementation requires efficient data coordination through the combination of different software and hardware.

There are a variety of tools that can be used to develop a fully coordinated BIM model, such as Autodesk Revit, Graphisoft ArchiCAD, Bentley Systems, and Dassault CATiA. These are the world-leading BIM software and platform vendors which can offer a comprehensive BIM solution for AEC industries. There is other software that can provide solutions for certain BIM tasks, such as energy simulations, bill of quantities, and renderings. Data coordination through different systems rely on interoperability (Smith, 2014a). On this basis, many software vendors are developing products and formats that can enable coordination with other software. Nowadays, according to personal observation and practice, different software can share data through the installation of API, enabling the connection to establish a better workflow. Thus, a detailed BIM model can be developed through the combined usage of different systems.

The requirement of development details for the BIM modelling process is being explored by industry and academia (Latiffi et al., 2015). The BIM model itself cannot possibly contain all building information due to the complexity of the building project (Chen & Luo, 2014). It is unclear what exact type of information is required for certain evaluation purposes (Cao et al., 2015). From personal BIM practice in a design company, to match a BIM model completely with a 2D drawing is not possible, since many 2D symbols have very low levels of detail. Therefore, during the 3D development process, most building components need to be designed instead of modelled. The model detail referencing code regulates to what depth the building component needs to be modelled (MOHURD, 2018), although with a low level of 2D drawing, there is no information for a 3D model to reference. Hence, the type of information needing to be created in a BIM model for improving design management needs to be tested.

Providing a clear modelling guidance will enable design teams to better integrate building data and information into a BIM model (Knotten et al, 2017). Strategies and steps to develop a BIM model at each design stage need to contain different detail levels to avoid either insufficient or too much information (Abou-Ibrahim & Hamzeh, 2016). The information builds at each design stage need to be sufficiently correct for design evaluation and assessment (Uusitalo et al., 2019).

The suitable level of information detail at each stage of the building development can lead to a consistent flow of data (Svalestuen et al., 2018). The data in BIM model development is an accumulative process (BIMforum, 2019).

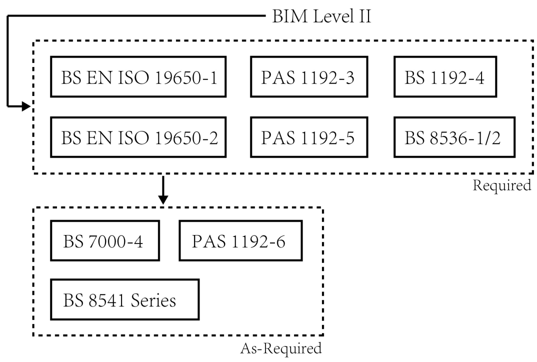


Figure 2.3 i: BIM Standards and Protocols (Yang et al., 2019)

(Figure 2.3.i) shows the required standards and codes of BIM Level II, which consists of PAS and BS. ISO 19650 is developed based on these standards. A BIM model falls into three categories, according to ISO 19650-1/2: Graphical Information, Non-Graphical Information, and Documentation. Graphical information needs to contain all required shapes and sizes of building components, while non-graphical information needs to include all property data (manufacture, cost, etc.) (ISO, 2018a). Documentation is a long-term archive solution, which requires data to be securely stored with convenient accessibility (ISO, 2018a). The information produced in a BIM model is accumulative and is required to integrate data for certain purposes of project operation (Elmualim & Gilder, 2014). ISO 19650-1/2 has defined Project Information Model (PIM) and Asset Information Model (AIM) in accordance with Project Information Requirement (PIR) and Asset Information Requirement (AIR), which is aimed at the Asset Management System. The overall aim of developing a BIM model is to retrieve specific information for specific tasks (Ingram, 2019). Therefore, AIM is the final delivery in BIM implementation.

The visualization process of design development is based on a coordinated BIM model (Zada et al., 2014). BIM models include multiple properties and characteristics beyond geometries, and these properties can be presented in a visualized way (Park & Kim, 2013). The visualization of the design process includes spatial coordination, which highly depends on the detail of the geometric model (Uusitalo et al., 2019); energy analyzation, which relies on integrated non-geometric information (Singh & Geyer, 2020); and quantification evaluation based on both geometric and non-geometric data (Wood et al., 2014). As a result of the findings, the level of detail of a BIM model is considered as the backbone of BIM implementation.

Although many AEC companies focus on BIM modelling, the development of a comprehensive visualized information model is the foundation of BIM implementation (Eastman et al., 2011). However, according to the literature review and personal observation, most BIM models are developed in an invalid way (Bryde, 2008), lacking in detail or even containing incorrect information (Biljecki et al., 2016). Incorrect information will lead to incorrect data coordination (Abou-Ibrahim & Hamzeh, 2016), and the lack of detail will impede further data analysis (Oh, Lee, Hong, & Jeong, 2015). Building projects include massive numbers of components and objects, and it is almost impossible to model each detail in an actual way (Uusitalo et al., 2019). To choose the most appropriate detail level during each design or construction stage can help the building project to implement BIM most efficiently (Svalestuen et al., 2018). Personal experience in the BIM modelling process has shown that it is quite hard to choose the most suitable detail level during the different design stages for each of the building components. The precise requirements for visualization and spatial coordination purposes are different from component to component (Yoders, 2014). Therefore, it is unclear if suitable modelling detail will cause inefficiencies in BIM development.

Finding a suitable data visualization strategy can help design teams to increase BIM utilization during the building design process (Juszczyk et al., 2016). BIM consists of geometric information and non-geometric information, which is aimed at developing a coordinated, visualized presenting solution (ISO, 2018a). An efficient data visualization solution during each design stage will increase the efficiencies in design evaluation (Koskela et al., 2018), while an appropriate presenting method can help both design team and client team to collaboratively assess the building project (NIBS, 2017). Building contains massive amounts of data from different design disciplines, and to correctly present the demanded information through model rendition will increase the data coordination and management (Reddy, 2012).

The visualization of information data has multiple tools and solutions (Marcinkowski & Banach, 2020). However, how to efficiently present to both design and client team is still under development, according to literature reviews. Project data can be collected on-site through surveying equipment, such as laser scanner, GNSS, and panorama cameras. There have some high-cost commercial solutions, but it is unclear how to affordably integrate those data. The data exchange and integration are highly dependent on the type of file format (Laing et al., 2014), while the compatibilities of each file affect the efficiencies of data coordination (Lee et al., 2019). Moreover, if the coordination process is too complex, it will slow down the building design process (Karen, 2015). According to the literature review, there is lack of low-cost integration solutions to comprehensively integrate various collected building data for visualization purposes. Therefore, finding a suitable way to implement the data visualization can enhance design coordination.

2.3.4.1 Information Management

Building design is a complex process with the involvement of multiple professionals and multiple development stages, which requires a high level of coordination of information to deliver the product. The three importance of design management is highlighted. Three most important factors to impact design management are: spatial and functional coordination, data visualization, and project understandings. Design management is crucial for satisfying the functional, budget, and appearance perspectives of a building project. The design manager needs to review carefully what is required from clients and to produce the design to satisfy the relevant demands for ensuring the design can be delivered with the correct content. Information production is a process of design and modelling, which is aimed at satisfying the relevant requirements from different aspects.

The role of design management is to ensure that all the information is produced and developed to the correct level of detail in order to avoid any mistakes and errors. It is highlighted that sufficient performance of design management will increase the quality of design documents, which will positively impact project development. The data transmission process needs sufficient management to ensure the correct data are sent and received for later coordination and development purposes. Design management during the data transmission process involves three aspects: the data between different design disciplines, the data between design team and client team, and the data between design team and third-party technical teams.

The designed building data need to be integrated and coordinated for many reasons, and these data are not limited to graphical geometric information for spatial clearance purposes, but the non-graphical information is also required to be integrated for functional and asset management purposes. The design management team needs to ensure that the correct information is being delivered on schedule both before and during the design delivery process. The quality and efficiency of design delivery will help different project participants to better control the project. It is argued that the design documents need to be presented in an understandable way to improve the reviewing and assessment process. The successfulness of the delivery process has the potential to increase design business operation performance.

The UK government has divided BIM implementation into four stages, from level 0 to level 3 (BSI, 2013). Level 0 starts with no data coordination while level 3 enables different data to fully interoperate (BSI, 2013). According to data interoperation, BIM strategies are divided into Open-BIM and Closed-BIM (Du, 2013). Open-BIM uses an exchangeable data format such as IFC, XML, etc., while Closed-BIM can exchange data within the software vendor’s products (NIBS, 2015). To better coordinate data during BIM implementation, ISO 19650-1/2 highlights the definition of Exchange Information Requirement (EIR), to better regulate the data flow in project development. Therefore, the Common Data Environment (CDE) was introduced to improve data transmission during the building design process (ISO, 2018a). According to ISO 19650-1/2, data has four statuses, which are: Work in Progress (WIP), Shared (Client Shared), Published, and Archived. In the first three status, data is placed in CDE while in archived status, data need to be moved elsewhere for long-range storage (ISO, 2018a).

BIM itself is still under development. Standards, Methods, and Procedures (SMPs) are not sufficiently sophisticated for practice in building projects, according to personal observation and experience from the industry. BIM is still struggling to achieve certain tasks during project development (Cao et al., 2015). BIM implementation strategies are being studied and researched, according to literature reviews. It is unclear what exact strategy is most efficient in BIM practice for building design development, despite the existing tools and platforms. The types and quantities of resources needed for BIM practice need to be identified before the project (ISO, 2018a). Moreover, the BIM modelling software itself is developed based on BIM demand (Smith, 2014b), hence unsophisticated BIM implementation strategies cause insufficient software development. The result is a negative cycle. To validate an efficient BEP for the design phase will lead to a successful building design business.

As the advantages of BIM implementation have been recognized, BIM adoption in AEC industries is increasing (Kassem & Succar, 2017). However, according to the literature review, many reports have stated that BIM has not been fully applied during the entire building life cycle, and most BIM practice is inefficient. Design companies and construction companies are two of the major BIM practice industries (Jernigan, 2008). Although there has been significant BIM implementation during the asset management stage, the practice is inconsistent with design and construction (Dixit et al., 2019). Construction Operation Building Information Exchange (COBie) is developed for the building operation phase by referencing information of each component from the construction phase (NIBS, 2015), and the construction information is inherited from the design phase (Reddy, 2012). Therefore, the data and information are inconsistent during the implementation of BIM in a building project.

Developing a clear BIM Execution Plan (BEP) will increase the efficiencies of design teams' BIM practice (ISO, 2018a). The design team needs to clarify what is expected from BIM adoption (Holzer, 2016). From the expected demand, the next step is to choose the most appropriate tools (Smith, 2014). Then the design team needs to consider the methodologies of BIM delivery, for example, what BIM outcomes to deliver and how to deliver these contents (ISO, 2018b). A clear BIM implementation strategy will enable design teams to increase the data coordination of a building development (Shillcock & Cao, 2019). Moreover, positive outcomes from a well-organized BIM practice will enhance the understanding of BIM in a holistic manner (Elmualim & Gilder, 2014).

The understanding of BIM in many Chinese industries is limited to the modelling process, according to the China BIM annual report (2019), and the view of BIM as equal to Revit models is a common misconception. According to market research, many Chinese BIM companies provide service limited to Revit modelling based on the existing 2D diagrams. Many BIM training institutes are mainly providing Revit courses, according to observation. Despite the involvement of other software, for example, the 4D and 5D simulation tools, overall, BIM practice is still limited to digital models, according to the quantification statistics from secondary data. There is lack of understanding of BIM from an information management perspective (Alreshidi et al., 2017), and most AEC industries are still using the traditional way of managing information under BIM implementation. The investment to adopt BIM practice is relatively high for most companies, according to official statistics. Therefore, invalid use is making BIM redundant and is causing extra workload, thus increasing companies' resource input (Juszczyk et al, 2016). Hence, a misunderstanding of the BIM process is hindering AEC industries in improving their business performance.

2.3.4.2 Impact of ISO 19650 on Information Management

ISO 19650 was introduced in December 2018 to regulate information management in construction projects. The standard comprises five parts: the first part discusses the general concept; the second part regulates how the digital assets need to be delivered during the building project; the third part regulates how the asset needs to operate; the fourth part regulates how the information needs to be exchanged; and the final part regulates the security aspect of the information. By July 2021, all parts were officially released, with the exception of the fourth part.

ISO 19650 was developed based on the UK PAS 1192 series, which inherited those key aspects concerning the management of project information (Shillcock & Cao, 2019b). The key concept of ISO 19650 is how to structure and organize management of information in AEC projects from requirements to operations. It provides a life-cycle management for the reference of developers, engineers, project managers, and stakeholders. This research was inspired by the first two parts of ISO 19650, whose features are mostly based on the second part, which is delivery of the digital asset during project development. This is because all the delivery processes include how information is procured, planned, and produced; hence it is aligned with building project development. Although the fourth part has not yet been released, its concept and aspects are included in the second part. Therefore, this part of the literature review explored ISO 19650-2 in-depth, to discover how information delivery is impacted.

There are three main parties, according to ISO 19650 (2018): the appointing party, the lead appointed party, and the appointed party. The appointing party is the clients' representative; since the client usually does not have enough professional knowledge to manage the entire project, an appointing party is hired on behalf of the client. The lead appointed party is the one who directly communicates with the appointing party, so the lead appointed party is more like a main contractor, who later sub-contracts each task to individual professional teams. The appointed party is the one who carries out the work based on the assigned tasks and is only responsible to the lead appointed party. The information flow is hierarchical, according to ISO 19650, is, and is only transferred from one level to the adjacent level.

The procurement of information is based on the information requirement. The requirement of information is based on the client company's day to day strategic development, according to ISO 19650-1 (2018). The Organizational Information Requirement (OIR) is the foundation, since all activities need to satisfy the relevant client demand. Based on OIR, the Exchange Information Requirement

(EIR) is developed to regulate how the information needs to be accessed and exchanged for delivery of the data. In this process, the information container, software, and data format are defined for enabling the unifying of the information production process. Project Information Requirement (PIR) is required in order to regulate how the project meets with the organization's development strategy; and the Asset Information Requirement (AIR) is developed based on the PIR to satisfy the daily asset operation. Subsequently, the Asset Information Model (AIM) and the Project Information Model (PIM) are developed for satisfying the requirements of the AIR and PIR.

During the process of defining the information requirement, the principle of SMART needs to be considered. This framework was developed by Peter Drucker in his book "The Practice of Management" (1954). SMART stands for Specific, Measurable, Achievable, Realistic, and Timely. Specifically, the information needs to be precisely defined according to requirements and demands. For Measurable, the information needs to be defined in a way that can be checked for quality assurance once finished. For Achievable, the requirement of the information needs to be defined within the capability of the appointed party. Realistic is similar to Achievable, in terms of ensuring the information can be produced to a reasonable scope. Timely relates to when the information can be completed in production. The above criteria provide an accurate reference for information production, while a similar concept can be applied to building design, a clear requirement can help the design team deliver the information on target.

ISO 19650 defines the need for clear aims for information production. PIR and AIR satisfy the OIR, and EIR satisfies PIR and AIR, while PIM and AIM are for final delivery of the information production. With the clear requirement of information production, the client's team needs to find the suitable party to produce the information. In this case, a clear task requirement needs to be issued, in the form of EIR, since this contains information from both PIR and AIR for defining the building project requirements. The purpose of EIR includes defining all the required standards, key decision points, and all the referential criteria according to ISO 19650 (2018). The appointed party needs to consider their ability based on the EIR requirement from and format their response as per the Building Execution Plan (BEP).

BEP is the response to EIR, which enables the appointing party to understand the preliminarily plan from the appointed party regarding resources and how the required information is to be produced. BEP includes personnel skills, relevant knowledge, and IT mobilization of the potential appointed party. Based on the given BEP, the appointing party examines whether the appointed party has the capability to accomplish the work. BEP is classified as pre-BIM and post-BEP; pre-BEP is used in the tendering process while post-BEP is used once the tender is complete. A post-BEP consists of more details, including a schedule of each information production known as the Task Information Delivery Plan (TIDP) and Master Information Delivery Plan (MIDP). The MIDP consists of multiple TIDPs. With a very clear BEP response to the EIR, the procurement of information is complete.

The importance of information procurement is in ensuring that the appointed party can successfully complete the work, and in clearly defining which and how information is produced. Through the procurement of information, the information production schedule can be made, which enables control of the entire process of project delivery. In building design projects, the concept of ISO 19650 can also be applied, since client requirement is considered as information requirement, which can be defined as EIR regarding how the client wishes the project to be. Building design also involves the tendering process, where the building design company shows the client their resources and capabilities to carry out the work. More importantly, the building design delivery needs to meet client requirements as regards spatial and functional aspects.

Once the appointment is confirmed, the appointed party needs to give a very clear plan as to how information is produced. According to ISO 19650, the information planning stage is also referred to as the mobilization stage, which consists of preparing all the required resources such as personnel, knowledge, and technology. To link with building design development, relevant technology is related to which tools are required to accomplish the design tasks, for example, the relevant software, hardware, and mobile devices. The knowledge relates to how these software and tools need to be used, and the required process. Resources comprise both human and IT capital. As regards human capital, it is important to ensure that all people have acquired the required knowledge to do the work, whilst for IT capital, all software and tools must meet requirements in terms of type and version.

Standard, Methods, and Procedures (SMPs) are also determined to prepare information production. The SMPs need to be tested by the appointed party prior to implementation to ensure the proposed solution works. Building design involves a large quantity of local and national building codes for the purpose of security and usability. Therefore, before the production of building design information, careful consideration is required in choosing which standards apply in order to satisfy the regulations. Building design methods involve collecting the necessary data to produce the required information and deliver the content. During the planning stage of building design, the procedure relates to how each step of the development needs to be conducted to achieve the production. Therefore, since the building design itself is the production of building information, application of ISO 19650 criteria during development of the building project will improve performance.

Relevant training is required during the information planning stage to satisfy demand at the procurement stage. This training includes specific knowledge and skills; in building design, a professional understanding of the development process is required and since building design comprises multiple disciplines, a comprehensive knowledge of each discipline is required according to the relevant building system. Knowledge of the local environment (e.g., site context, climate) is also required in order to ensure that the design intervention is relevant in terms of building and site. Skills required include communication, collaboration and integration and, in particular, operational skills regarding to the software and tools to ensure correct use of technology.

ISO 19650 (2018) also defines the responsibility of each person in the information production process, specified as RACI (Responsible, Accountable, Consulted, Informed). Since, according to the criteria of ISO 19650 there is no information manager in charge of the production process, everyone in the project team has their own role. A similar concept is applied to building design development during the design production, whereby each piece of information can be traced back to a specific task team and to the responsible person. In this way, efficiency in information management of building design development is improved.

According to ISO 19650, the production of information needs to be clearly scheduled, with each task produced by the appointed party, also referred to as the task team. A clear schedule known as the Task Information Delivery Plan (TIDP) is produced by each task team, showing completion dates. There are multiple TIDPs throughout the information planning process, and the Master Information Delivery Plan (MIDP) is a further integration of the schedule from each task team. This schedule can also be applied to building design development, since building design consists of multiple disciplines, and each discipline has a task team. Efficient and accurate integration of these schedules enables the project to precisely control the delivery schedule.

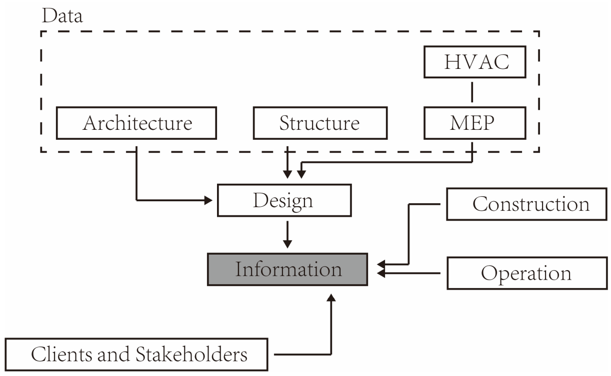


Figure 2.3 j: Findings of Roles of Common Data Environment (CDE)

Another important aspect of ISO 19650 during the information planning stage is regulation of information containers, i.e., where data is stored and how to access it. A Common Data Environment (CDE) is required for data production, exchange, and storage. The advantages of CDE are highlighted in the centralization of project data (Figure 2.3.j). According to ISO 19650, all information production from the development cycle needs to be conducted in the CDE. Despite the limitations of current supporting technology to achieve this, its core concept shows the value of the potential capabilities. In comparison with the traditional method of information production during building design development, a CDE-based information production can avoid loss of data, enabling structure of data to ensure all project members can access the right information in a timely manner. With improved data accessibility, collaboration in design development can be enhanced, which positively impacts the business operation.

The production of information structured according to the criteria of ISO 19650 (2018) involves tasks being assigned by the appointing party to the lead appointed party, and then to the appointed party, while the delivery of information operates vice versa. The hierarchy of information production ensures each step of production is reviewed, checked and approved through

Standard, Methods and Procedures (SMPs, hence ensuring production quality. These criteria in information production and delivery can also be used in the building design development process because the design team needs to submit the final documents for construction. According to ISO 19650, the information can only be accepted or rejected in a holistic way; partially accepted information is not allowed. Building design delivery meets with this requirement since the design team cannot partially submit the design documents for government approval and so, prior to delivery of final information, the completeness and quality of the information needs to be checked.

ISO 19650 is aimed at ensuring that all delivered information meets the requirements, in order to minimize risk regarding changes and modifications. Hence, before the project is started, there needs to be a very comprehensive assessment of demands and needs. The feature of each character is discussed and linked with building design activities to identify potential solutions to improve building information coordination. Information procurement discusses how the mobilization of IT and human resources needs to be considered; information planning discusses what and how information needs to be produced, while information production discusses the specification during the information production. The building design processes are related to understanding how ISO 19650 can be used to impact the development of a building project.

According to ISO 19650, relevant technology is used to ensure that all SMPs guarantee the quality of information production. One of the most important technical solutions is the Common Data Environment (CDE), although this is not yet sufficiently sophisticated to support current building projects. ISO 19650 requires all information be produced, shared, and delivered in CDE. Information has four statuses, and three of them are included in CDE: Work-In-Progress (WIP), Shared/Clients Shared, and Published. The last status needs to be removed from CDE for long term achievement while production needs to be approved before entering the next stage. Therefore, the role of CDE is significant during the entire process of information production. It requires the support of good internet speeds such as 5G and WiFi-6 due to the large amount of data being streamed. CDE provides a good collaborative environment by integrating PC and portable devices through the convenience of data accessibility. In CDE, the review, check, and approval process become more alive, which enables live data updates.

To satisfy ISO 19650, information should be produced according to suitable SMPs, focusing on the review, check, and approval process at each stage of information delivery. Collaboration is considered as one of the most important factors in building design development. Since design comprises numerous disciplines, poor collaboration will likely lead to project failure. Collaboration in building design can follow the criteria of ISO 19650 by using the relevant technology and SMPs to establish the collaborative environment within the project team. Collaboration is not merely as simple as using technology, but instead needs to focus on the management of the entire development process at each step.

Furthermore, to apply the criteria of ISO 19650 to building design development during the design production stage, information in building design needs to follow the Clear, Complete, Consistent, Coordinated, and Correct process, according to findings from various theories and guidelines. Clear relates to the information needing to be produced according to expectations. Complete means the information needs to be produced by following the schedule plan Consistent reflects that all information is produced according to the SMPs. Coordinated shows that the functional and spatial information is correctly produced to ensure no physical clash. Correct means that all information meets with the criteria of the relevant codes and standards. In following the above criteria, quality of production in building design development can be improved.

During information production, data needs to be exchanged for integration and coordination, for ensuring the efficiency of the data exchange process, and all the technical aspects for unifying production tools, such as the version of the software and firmware, type of data format and communication tools. As regulated by ISO 19650, all the data production and exchange need to be conducted in the CDE. However, due to the limitation of current technology, CDE cannot satisfy the entire data exchange process. Therefore, during the production of information, the task teams need to use agreed tools to ensure data compatibilities and exchangeability. To link with building design practice, the related information includes both data from the data collection process and the data produced during design development. To apply the ideas from ISO 19650, the design team needs to choose the appropriate methods to ensure all the data can be used collaboratively.

One of the most concerning issues to be dealt with during information production is that of the schedule. Despite the existence of TIDP and MIDP, due to the complexity of a construction project, it is difficult to adhere to the schedule. Although the adoption of ISO 19650 can help to improve information coordination, many problems in building design remain unsolved. There is no precise way to control production in a timely manner due to frequent modification requests. In fact, according to the personal experience of the researcher, in Chinese building design companies, design production rarely follows the schedule. The schedule itself directly affects the productivity of the design team, which directly impacts the business operation performance of the building design company. Therefore, beyond ISO 19650, more methods and specifications need to be explored to fill this research gap for enhancing productivity in building design.

Table 2.3 a: Impact of Features of ISO 19650

ISO 19650	Access	Response	Process
Communication	√		
Collaboration	√	√	√
Details	√		

(Table 2.3.a) shows the impact of core features of ISO 19650 on each issue of information coordination in design development. The Common Data Environment (CDE) of ISO 19650 enables the project team to access design data for detail development during communication while in collaboration. The RACI Matrix of ISO 19650 guides the responsibilities of each person during the collaboration process to ensure all the information is correctly associated. BIM Execution Plan (BEP) and SMPs from ISO 19650 help information production to be well scheduled and developed during the collaboration. The interrelations are listed in (Table 2.3.a), which shows ISO 19650 mostly impacts collaboration during information coordination.

2.3.4.2 Impact of LOD 350 on Information Development

Level of Development (LOD) was first introduced by the American Institute of Architects (AIA) and is updated annually through the BIMforum (2019). China introduced Level of Model Definitions (LOD) in 2018, implemented since June 2019 (MOHURD, 2018). AIA classifies LOD in five levels, from 100 to 400, and LOD in the Chinese regulation is classified into four levels from 1.0 to 4.0. Despite the difference in naming, the functions are similar, aimed at providing a reference for development of the BIM model. According to literature reviews of relevant codes and standards, the comparison between two LODs are shown in (Table 2.3.b), with different LOD levels used at different design stages. For example, LOD 100 and 200 (LOD 1.0 and 2.0) are used in concept design, LOD 300 (LOD 3.0) in construction document design, and LOD 400 (LOD 4.0) in construction instructions (BIMforum, 2019; MOHURD, 2018). LOD is an accumulative information process, where each LOD level needs to include all details from the previous level (BIMforum, 2019).

Table 2.3 b: Definition and Comparison of LOD in US and China

Level of Development (AIA)		Level of Model Definition (China)	
LOD 100	Symbol for representation	LOD 1.0	Project Level
LOD 200	Graphical and Non-Graphical information	LOD 2.0	Functional Level
LOD 300	Specific system with correct geometry	LOD 3.0	Components Level
LOD 350	Interface between different systems		
LOD 400	Detail for assembling and installation	LOD 4.0	Parts Level

Multiple implementations of LOD have been researched and practiced. For example, LOD can assist in the assessment and evaluation of Quantity Survey (QS) in the early stages of design development (Wood et al., 2014), LOD can provide the design team with a clear reference for lean design management purposes (Uusitalo et al., 2019), LOD can improve overall performance during building design development (Svalestuen et al., 2018), and LOD can provide specific content requirement for building projects to increase the collaboration between design disciplines (Latiffi et al., 2015). Furthermore, without LOD guidance during the data coordination process, the design team will face either lack of information or excessive information, which will negatively impact design management efficiencies (Grytting et al., 2017). As a result, LOD is considered an information guideline in the development of BIM models, aimed at increasing data coordination from stage to stage during the building design process. (Figure 2.3.k) shows the usage of LOD 300, LOD 350, and LOD 400 during the building design stage.

LOD 300 provides an approximate accuracy for referencing during design development. Many 3D information models are developed up to this level and are directly updated to LOD 400. However, the workload for LOD 400 involves a massive amount of modelling; if the model in LOD 300 is not well coordinated, multiple errors will occur. Therefore, a transition via LOD 350 is required for ensuring all information is correctly coordinated (Figure 2.3.k). According to building project regulations in the Chinese AEC market, the design company needs to be responsible for the project until the construction completion. The reduction of mistakes during construction will save design company time and effort. Therefore, the adoption of LOD 350 may enable further optimization during the design development to improve delivery quality.

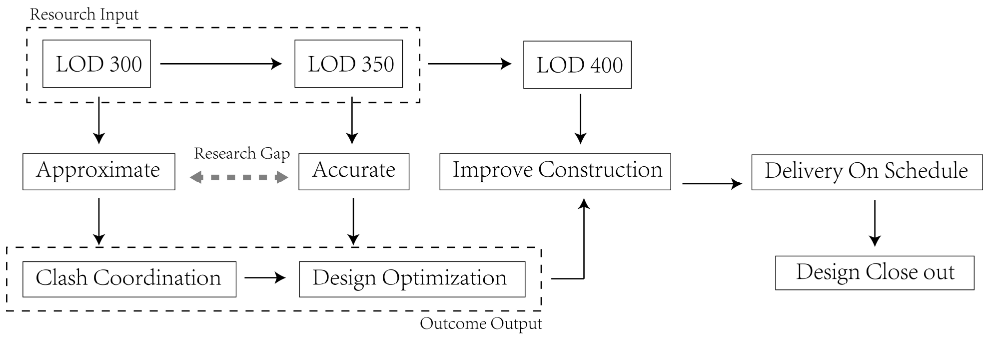


Figure 2.3 k: Impact of LOD 350 and LOD 400 (Yang et al., 2020)

Moreover, beyond the design development, LOD can impact the design process in the long term. For example, LOD is important in sustainable design because energy simulation requires a well-coordinated information model (Dupuis et al., 2017), Dautremont et al. (2019) have verified that parametric design needs coordinated material data to contribute to sustainable design. The implementation of LOD allows the BIM team to deliver a model that contains the correct information for certain task assessments (Grytting et al., 2017). Therefore, a correct information model can contribute to Facility Management (FM). Accordingly, Dixit et al. (2019) validated that LOD can impact on decision making in FM, and also LOD can impact on integrating BIM with FM. The FM process requires accurate project information, which demands a high accuracy of COBie data accumulated in the construction phase (Teicholz & Foundation, 2013). Hence, the adoption of a correct level of information detail can increase data coordination of the design process, which subsequently can improve the design management.

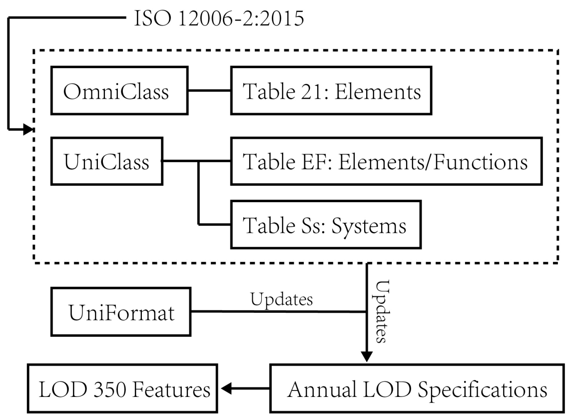


Figure 2.3 l: Standards of Elements Classification (Yang et al., 2019)

Building elements are classified as OmniClass and UniClass, as regulated by ISO 12006 (Figure 2.3.l). LOD specification is based on the building classification and is updated annually. The features of each level of LOD are linked with those characters of the building elements. The modelling of the BIM model needs to use different software - for example, to model an accurate geometry shape in Rhino - and to be imported to Revit for developing non-geometric information. The design team needs to clarify what information is required to build, then choose the most suitable software accordingly (Marcinkowski & Banach, 2020). Hence, a clear LOD reference can help the design team to find the appropriate tools during BIM implementation. LOD provides a reference for data coordination (Fai & Rafeiro, 2014) and the visualization solution such as Virtual Reality and Mixed Reality require supportive data from BIM mode (Yoders, 2014). Therefore, a suitable LOD will contribute to the visualization process, and increase design efficiencies.

Despite the existence of LOD, the BIM modelling process continues to have multiple issues (Elmualim & Gilder, 2014). Since LOD is not compulsory in the Chinese AEC market, many design teams and BIM companies are not developing the BIM model in a correct way, according to observations. Most

BIM models used for spatial coordination purposes only reach LOD 300 level, according to observations in the AEC market. However, with the increasing complexity of buildings, LOD 300 is not sufficient to detect clashes for spatial optimization (Biljecki et al., 2016). Hence, during the construction phase, spatial clash issues are frequent, which requires further modification. For visualization purposes, although LOD 300 can develop sufficient geometry details for appearance assessment, it does not contain enough details for spatial evaluation, according to personal experience in building design companies (Figure 2.3.m). Therefore, a series of problems will occur due to insufficient design optimization. These issues include uncoordinated space, aesthetic disorder, and functional disconnection. Hence, a more accurate specification is required to improve this situation.

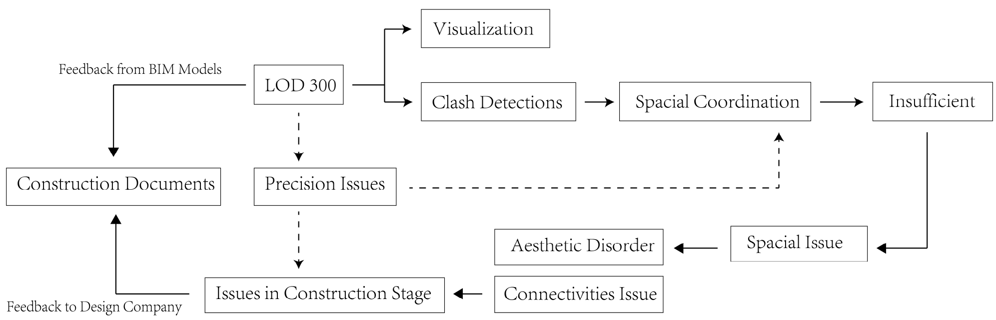


Figure 2.3 m: Limitations in LOD 300 (Yang et al., 2020)

LOD 350 was proposed in 2013, aimed at establishing the link between different building systems (BIMforum, 2013). Through LOD 350, each element needs to be modelled in actual geometry to inherit all properties from previous levels (LOD 100 to 300), then the connection components added to establish the interactions (BIMforum, 2013). LOD 400 is developed for construction instruction purposes, containing all required detail for fabrication and installation purposes (BIMforum, 2019). According to studies based on AIA LOD Specifications (2019), geometric information built in the BIM models is increasing from LOD 300 to LOD 400 (see Table 2.3.c). According to observations in the AEC market, most BIM models jump directly from LOD 300 to LOD. LOD 400 contains actual details for construction, requiring significant input and effort (Latiffi et al., 2015). Indeed, models developed in LOD 400 are considered virtual construction; however, if the LOD 300 model does not contain the correct information, modification in LOD 400 will require more effort, according to personal project experience. Hence, the adoption of LOD 350 during design development is especially important.

Table 2.3 c: Information Development in AIA LOD

Information	LOD 100	LOD 200	LOD 300	LOD350	LOD 400
		Graphical Information			
Shape	Generic	Approximate	Specific	Accurate	Actual
Size	Generic	Approximate	Specific	Accurate	Actual
Quantity	Flexible	Approximate	Specific	Specific	Specific
Location	Flexible	Approximate	Specific	Accurate	Actual
Orientation	Flexible	Approximate	Specific	Accurate	Actual
		Non-Graphical Information			
Material	Approximate	Approximate	Specific	Specific	Specific
Cost	Approximate	Approximate	Specific	Specific	Specific

AIA classifies geometry detail from generic to actual, according to LOD specifications (BIMforum, 2019). The geometry accuracy level accumulates across the BIM model development, as seen in (Table 2.3.c); the higher the LOD, the more geometric detail there will be. Chinese BIM standard “Standard for Design Delivery of Building Information Modelling” regulates geometric detail into four levels, from G1 to G4. According to the regulation, G1 is 2D symbols, G2 is approximate geometry and colour, G3 is for procurement, and G4 is for construction fabrication (MOHURD, 2018). In AIA LOD specification (2019), the term “Actual” is defined as for manufacturing purposes, and the term “Specific” for measurement purposes. To link these two standards, the G3 level is equivalent to specific detail and G4 level to actual detail (see Table 2.3.d).

Table 2.3 d: Geometric Details in Chinese LOD

Chinese	G1	G2	G3	G4
AIA	Generic	Approximate	Specific	Actual

Purpose	Schematic Design	Design Development	Construction Documents	Construction Fabrication

LOD contains both geometric and non-geometric information according to specifications (BIMforum, 2019; MOHURD, 2018). In Chinese standards, information detail is regulated into four levels, from N1 to N4. According to the regulation, N1 describes the project and organization information, N2 describes the materials and other properties, N3 needs to include production and installation information, and N4 should contain asset and maintenance information. AIA LOD specifications (2019) do not give a definition of information detail level; however, according to ISO 19650-1/2 (2018), Project Information Requirement (PIR) and Organization Information Requirement (OIR) meet with N1 requirements and Asset Information Requirement (AIR) meet with N4. There is a gap in N2 and N3 regarding the LOD level; N2 highlights the interrelation between each system and N3 highlights the manufacturing. Therefore, N2 can be matched with LOD 350 and N3 can be matched with LOD 400. The findings are presented in (Table 2.3.e). This study matches LOD 350 with Level 2 of Information Detail in project design phases.

Table 2.3 e: Non-Geometric Details in Chinese LOD

Chinese	N1	N2	N3	N4
AIA		LOD 350	LOD 400	
International	PIR, OIR			AIR
Purpose	Project Planning	Project Design	Project Construction	Project Maintenance

The definition of LOD 350 given by AIA is to establish the interaction between different systems (BIMforum, 2013). According to the LOD specifications (2019), the geometric and nongeometric information required in LOD 350 is different in each building system. The Chinese standard highlights that each model unit can adopt different geometric detail but needs to satisfy the application depth (MOHURD, 2018). To link these two standards, this research suggests an appropriate BIM model at LOD 350 level, each with building component needing to meet G3 and N2 requirements as a minimum.

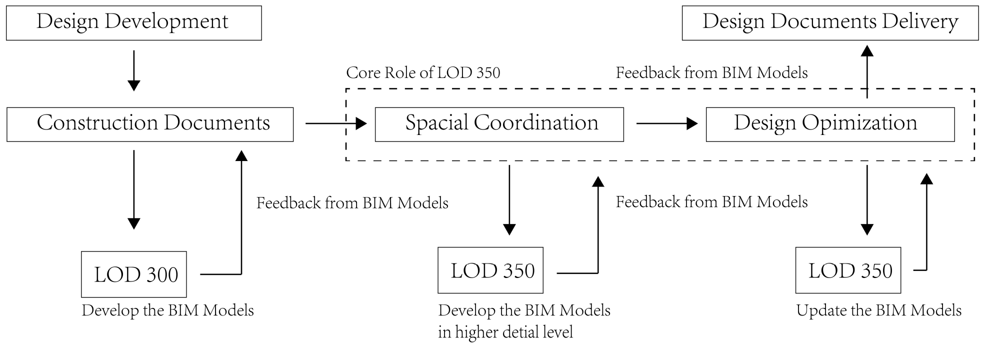


Figure 2.3 n: Role of LOD 350 in Design Coordination (Yang et al., 2020)

The appropriate LOD level can increase data coordination between different design disciplines (Fai & Rafeiro, 2014). Building design consists of multiple stages, which are Concept Design, Preliminary Design, Design Development, and Construction Documents Design. According to Chinese building design regulations, BIM can increase design coordination (Eastman et al., 2011) and LOD provides the reference for BIM model delivery during the design process (Latiffi et al., 2015). LOD 100 and 200 are adopted during the conceptual design stage to provide the spatial refence brief, while LOD 300 is developed during the construction document stage to conduct the spatial coordination (BIMforum, 2019). The role of LOD 350 is between construction documents and construction fabrication, aimed at developing more geometric information and providing further spatial optimization, according to findings in the previous section. The role of each level of LOD is illustrated in (Figure 2.3.n), which shows that LOD 300 is used in construction documents, and LOD 350 is further implemented for spatial coordination and design optimization. Therefore, with the adoption of LOD 350, the 3D information model can improve feedback regarding building design development.

A BIM model in LOD 350 level consists of every design discipline with integrated geometric and non-geometric information, according to AIA specifications. A fully coordinated BIM model can positively impact design visualization (Zaker & Coloma, 2018). Geometric information such as shape and location will impact the spatial coordination process while non-geometric information such as materials will impact the data analysis process, according to personal experience during BIM practice. Hence, through integrating different types of information, a comprehensive virtual building can be built for project assessment. The finding results according to literature reviews are presented in (Table 2.3.f). The difference between a model in LOD 300 and in LOD 350 level is that LOD 350 can more realistically reflect the building project through a virtual environment.

Table 2.3 f: Findings of LOD 350 Impact on Design Development

	Data Coordination	Data Analysis	Data Visualization	Data Assessment
Geometric	Spatial coordination	Clash detection	Walkthrough and Virtual Tour	Appearance assessment
Non-Geometric	Physical properties, Cost and Price	Light & Energy Simulation. Bill of Quantities	Photo-Quality Renderings	Sustainability assessment, Budget control

LOD 350 is more detailed in comparison with LOD 300, which can provide more reference for design management. The most significant feature at this level is the accuracies in geometric information and the establishment of system relations according to AIA LOD specifications (2019). Furthermore, the suggested geometric detail (G3) and non-geometric detail (N2) given by previous sections indicates that components in each building system need to follow specific details at accurate levels. From this aspect, a BIM model at this level is almost approaching a virtual construction model, which can provide enough detail for design and construction evaluation. Although developing a LOD 350 level BIM model requires extra workload, according to MacLeamy Curve (MacLeamy, 2004), the cost of design modification is increasingly high in the later project phases while having little impact on the project itself. MacLeamy (2004) has argued that efforts need to begin at the concept design stage instead of the construction documents stage. After the construction documents, it is extremely difficult to make further design modification. Hence, the characters contained in LOD 350 are of high value during the building design process.

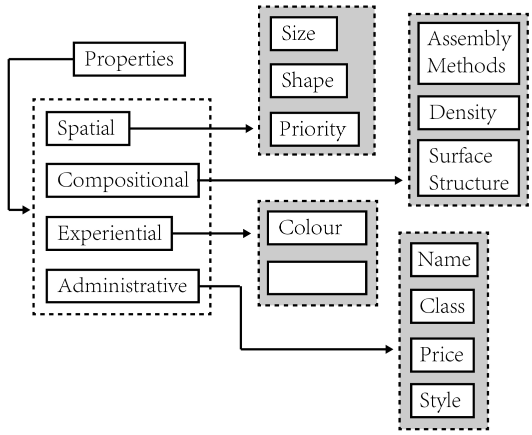


Figure 2.3 o: Impact of Properties of Building Elements (Yang et al., 2019)

(Figure 2.3.o) shows the properties of building elements, including spatial, compositional, experiential, and administrative. Spatial properties comprise size, shape, and priority, while compositional property comprises assembly methods, density, and surface structure. Beyond the physical properties, administrative properties include name, class, price, and style. LOD 350 consists of accurate physical properties for guiding the virtual development of building elements. Non-physical properties are included in non-graphical information for administrative purposes. Therefore, with sufficient and accurate building data, the building design can be better developed through the virtual environment for information coordination.

Building design development is a progressive process to accumulate all the demand requirements of the project (Imrie, 2011). The design progress requires the coordination of each design discipline (Hu, 2012). The outputs from each discipline are in a different format with various types of design documents.

Traditional, uncoordinated 2D-based design management has many limitations, which will cause design insufficiencies (Wang, 2019). Despite the implementation of BIM, according to personal industrial experience, there are many problems during design development, because without a clear BIM specification and SMPs, BIM is acting no differently to regular 3D models. Through LOD specifications, especially with high-level details, model development for building design has substantial reference during BIM implementation. Building comprises three stages (Figure 2.3.p), with LOD practiced mainly during the information production stage. With the integration of design data from different disciplines, building design can be better coordinated.

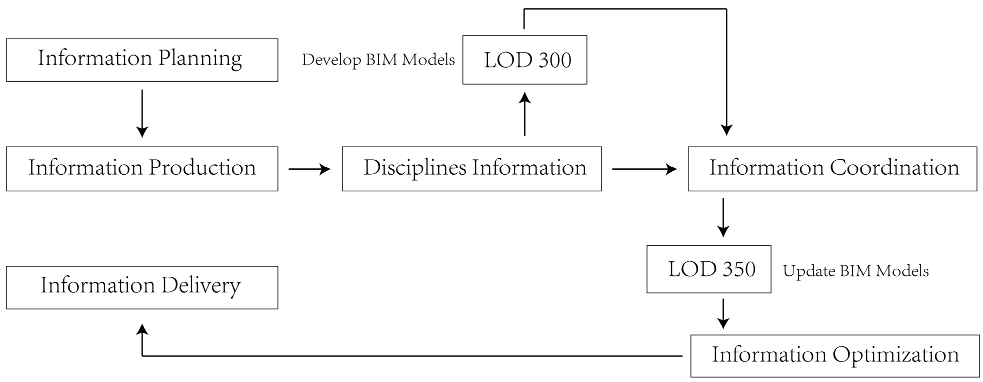


Figure 2.3 p: Position of LOD 350 in Building Design (Yang et al., 2020)

LOD is a progressive and accumulative process of building information. Low-level detail can help design teams to quickly generate design concepts while high-level detail can assist design teams to effectively evaluate the coordinated design (Grytting et al., 2017). According to RIBA 2020 Plans of Works, there is a stage called Spatial Coordination, which requires enough coordination from each discipline to avoid potential problems such as clashes. In the requirement of RIBA 2020, during the spatial coordination stage, the design team needs to check the design against relevant building codes for the preparation of technical designs.

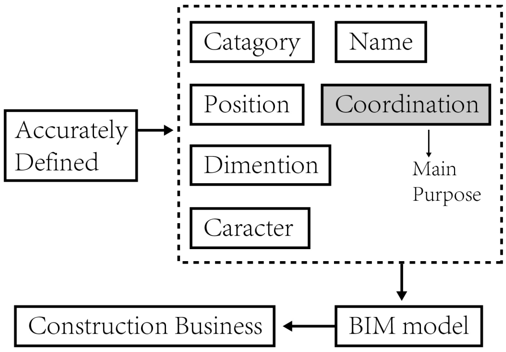


Figure 2.3 q: Impact of Model Accuracies (Yang et al., 2019)

The properties contained in LOD 350 meet the requirements to conduct sufficient spatial coordination during the integration process. The higher the value of LOD 350 the better during the technical design stage (Construction Documents Design) for the building virtualized simulation before entering the construction stage. BIM model at LOD 350 level can detect problems which cannot be found at LOD 300 level, which can further coordinate the space to minimize potential problems for construction.

Building design requires the integration of different workloads, consisting of planning, diagramming, and modelling (Eynon, 2013). This research proposes to use BIM to integrate the design process to increase design coordination. The high accuracy of building elements in the virtual environment is illustrated in (Figure 2.3.q). The implementation of BIM has been categorized into four levels, as regulated by UK BIM landing strategies, with uncoordinated design documents considered as the lowest level (LEVEL 0). Most of the current BIM practices are between Level 1 and Level 2, according to observations in the AEC market. Since Level 3 needs to enable comprehensive data exchange, there is no efficient solution to satisfy this requirement based on current BIM technologies. LOD 350 will enable the building design team to improve the management of design information (Figure 2.3.r), and the spatial and functional information can be coordinated for both inter and inner disciplines. Despite the additional workload and cost to develop BIM models to high levels of detail such as LOD 350, the returned value is higher than those inputs. The fully optimized BIM model at LOD 350 level can be further developed into LOD 400 level for construction instructions and facilities management.

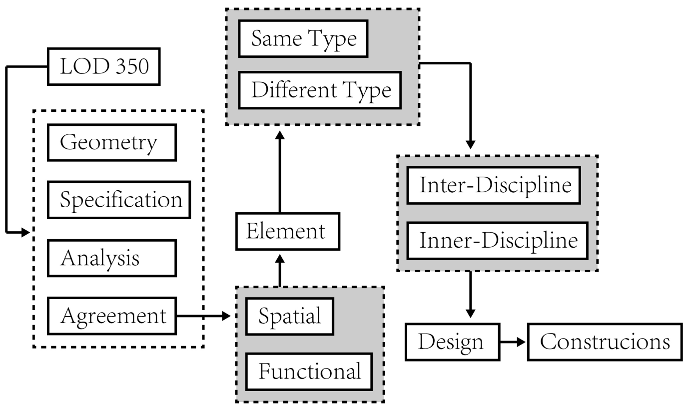


Figure 2.3 r: Impact of LOD 350 on the Coordination of Building Elements (Yang et al., 2019)

Building projects need to pass required checks and inspections prior to submission of design documents (Eynon, 2013). These inspections consist of both client requirement and governmental building codes (MOHURD, 2005). Moreover, the building assessment also needs to consider the impact to the surrounding environment (Maltese et al., 2017), the impact to local traffic, and the impact on commercial activities (Olawumi & Chan, 2018). Despite passing the relevant code, the building itself needs forward planning in long term perspectives (Dixit et al., 2019). The foundation of BIM is a fully integrated project model which can extract all required information for different purposes (Nicał & Wodyński, 2016). Three things need to be carefully checked before the design delivery, which are: Building Area Statistic, Clear Height Analysis, and Predictions for Post-Occupancies, according to the findings of this research. Adoption of LOD 350 can increase the detail level of the BIM model, with more effective information and increased accuracies during the design evaluation.

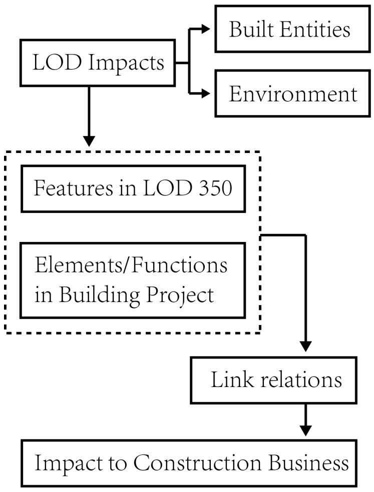


Figure 2.3 s: Linkage of LOD 350 with Building Projects

For the area calculation of the building using the traditional method, there are limitations (Glodon, 2020). Despite automatic calculation through the adoption of BIM, low level detail of BIM models also has certain limitations (Biljecki et al., 2016). With the intervention of LOD 350, BIM models can contain sufficient geometrical detail (Figure 2.3.s). With enriched features and accuracies, business operation of construction companies can also be impacted. Therefore, most potential geometries can be simulated and virtualized through the BIM model, which enables computers to automatically detect each valid space to the area calculation, according to the findings of this research.

Moreover, with the definition of each functional space, data quantified from the BIM model can be categorized into different parts. For example, the area can be specifically targeted to certain rooms or to certain activity purposes. Furthermore, with the intervention of LOD 350, areas can be calculated for building code purposes, and effective usage can also be generated via the high-level detailed model. (Figure 2.3.t) shows the interrelation between different building components regarding the impact of LOD 300 and LOD 350. Components from different disciplines are shown in the diagram. According to the findings, both

LOD 300 and LOD 350 can be used to impact the building design coordination because some elements do not require too much detail to avoid spatial and functional clashes.

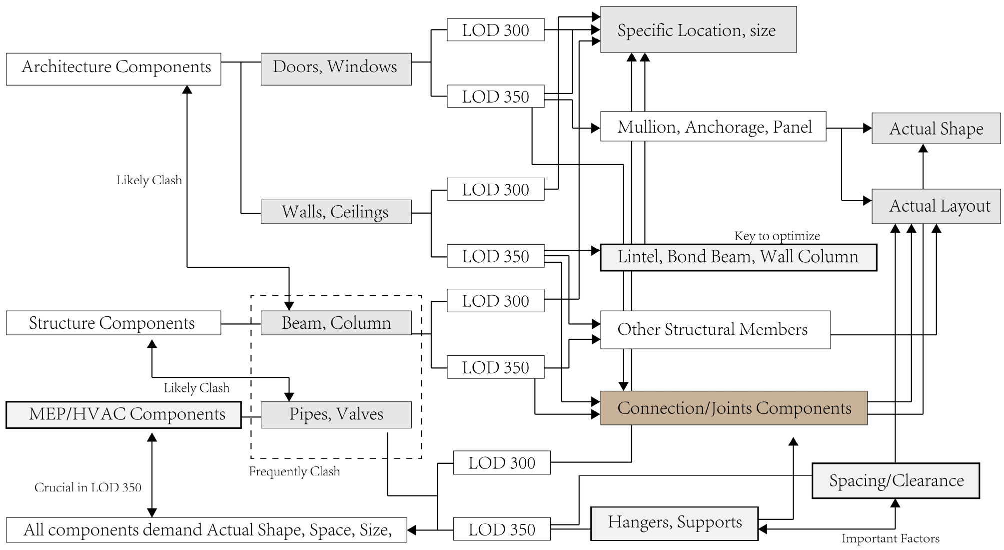


Figure 2.3 t: Impact of LOD 300 and LOD 350 on Building Elements (Yang et al., 2020)

The clear height analysis is crucial during building evaluation (Best, 2006). Since building projects consist of five disciplines, and each discipline is relatively individual according to the current building design environment, not only do frequent clashes occur, but sometimes fatal errors for clear height are occurring (Eynon, 2013). The insufficiencies during design coordination will cause lack of coordination among Architecture, MEP, HVAC, and other disciplines. Therefore, although each discipline has considered clear height from its own perspective, there may still be clashes with other disciplines, especially during integration. By nature, the traditional method of conducting integrated analysis has limitations due to all diagrams being 2D symbol-based diagrams with no representation of geometry (Hu, 2012). The depth of such diagram is equivalent to LOD 100, which is considered at the very beginning of BIM implementation. With the adoption of LOD 350, most of the building components are required to be virtualized into the actual graphical shape, which can help design teams to detect most potential spatial problems during the integration process.

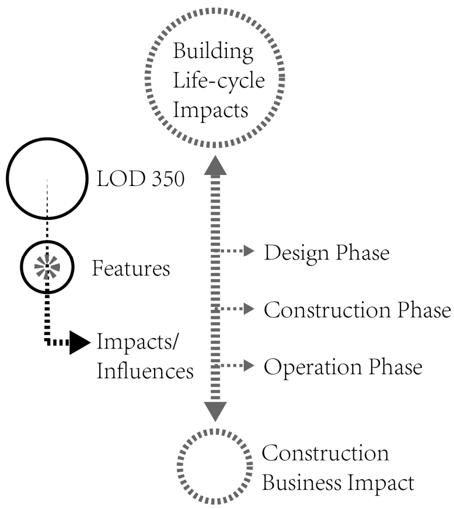


Figure 2.3 u: Impact of LOD 350 on Building Operation (Yang et al., 2019)

The Chinese building code requires a post-occupancy evaluation report following delivery to estimate if the building investment meets with the project plan and proposal. The traditional design method has technical limitations in terms of simulated activities prior to building usage because of limited analysis of design data (Glodon, 2020). Building projects normally require investment of huge capital; therefore, effective usage post-delivery is one of the most important aspects of the design development process, and the features of LOD 350 impact the business at the construction stage (Figure 2.3.u).

Both design business and construction business can be impacted due to the adoption of LOD 350 because during the model development, it will enable the design team to establish a virtual model and simulate potential activities through an immersive gamificative visualized environment. This process has been evaluated through three intervention studies in Chapter 4, Section 4.2 under the BIM environment for building design practice. The evaluation process under the created BIM environment will enable design teams to estimate potential problems and enable prompt modifications. The value of LOD 350 in this process provides a specification for creating a suitable BIM model.

A building design project is extraordinarily complex and needs to be well visualized during the coordination and evaluation process. According to the literature review, there are multiple solutions and technologies to conduct the visualization for design development. The experiments in Section 4.2 uses the proposition to evaluated the visualization procedures during each stage of building design, which has achieved the expected results. The value of the BIM model is realized during this process, especially through the adoption of the LOD 350 specification. The role of LOD 350 is considered as constructive guidance during the building development for enhancing the required information. The value of LOD 350 during this visualization progress focuses on two parts, which are: *Information Accumulation* and *Graphical Accuracy*.

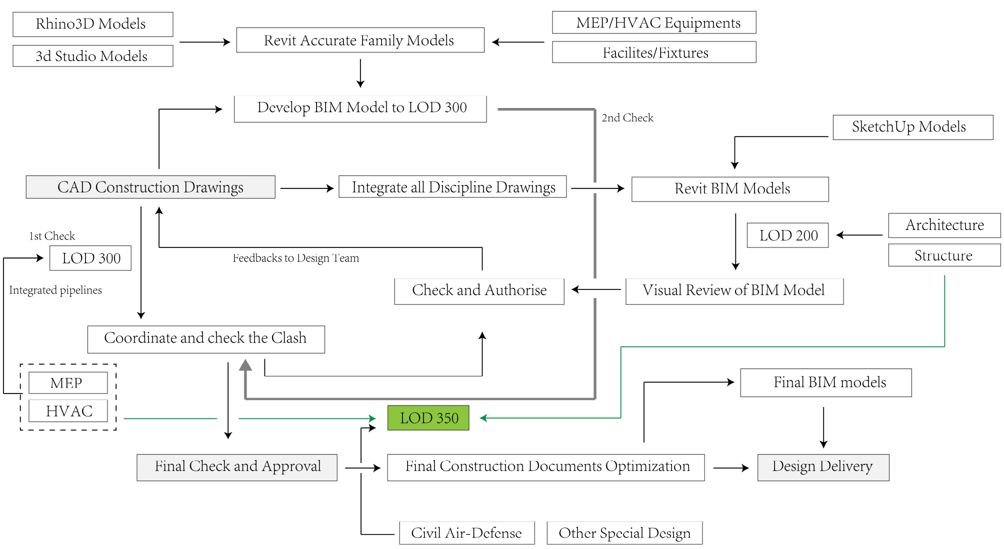


Figure 2.3 v: Building Design Development with LOD Intervention (Yang et al., 2020)

Building design is a very complex process which requires a large amount of information from planning to inspection before delivery for construction. The position of LOD 350 is highlighted in (Figure 2.3.v). The information from LOD

100 to LOD 400 is accumulated according to the specification of AIA Level of Development. The BIM model itself is a progressive development which requires the demanded information according to PIR and AIR throughout the building design progress. LOD 350 is adopted after the construction document design stage to intervene in relevant building connection components for further design coordination. LOD 350 consists of all specifications for previous levels, and this means the BIM model at LOD 350 level contains all properties from previous design phases. According to ISO 19650, the asset management system is based on the AIR followed by PIR (ISO, 2018).

The Asset Information Model (AIM) needs to be the final delivery of BIM implementation because it contains the demanded information. The visualized asset model from the design stage can help the design team and clients to better evaluate the investment. LOD 350 helps to construct the Project Information Model (PIM), which will enable extraction of the demanded assets for different purposes. Therefore, the accumulative information during BIM development can help the coordination and management of the building design project.

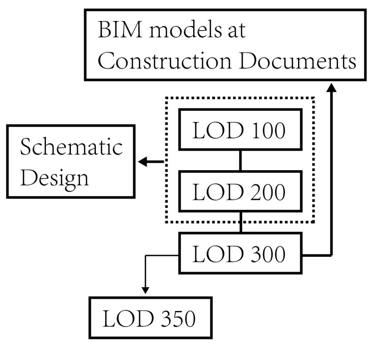


Figure 2.3 w: LOD in Different Design Stages (Yang et al., 2019)

The visualization process requires the actual spatial representation of the building component, according to the results of this research. The traditional visualization solution for client presentation is based on separative geometric models, which are uncoordinated with 2D drawings (Shih et al., 2017). In traditional SMPs of design development, the formal documents are issued in 2D symbol-based diagrams, which cannot represent their relations in spatial coordination. The importance of 3D information modelling is being recognised, and by using different levels of LOD the building design can be progressed entirely through a 3D-based virtual environment (Figure 2.3.w). Based on the researcher's personal industrial experience and observations, the 3D rendering images are being developed additionally in different design software.

The problem with this is that the built 3D components cannot represent the design documents, which will cause differences between actual buildings and designed buildings. Hence, the visualization for design evaluation will not be exactly accurate, which subsequently will cause many issues. The implementation of BIM is to integrate all graphic and non-graphic information into a single model to reflect the actual building situation. The properties of LOD 350 will enable the BIM model to contain the actual geometries to represent the spatial relations.

LOD 350 comprises accurate and sufficient detail in the form of graphical information, which can support the quantification process following completion of the building design documents (BIMforum, 2020). The traditional method of quantification for cost estimation is using the 2D LOD 100 and text-based design documents, which have limitations in terms of covering all the building components to issue a reliable Bill of Quantities (BOQ) for the tendering stages. With the potential error in cost due to uncertainties, both stakeholder and construction company may be exposed to risk in their overall budgets (Ahmad et al., 2018). These uncertainties are usually caused by lack of detail in the design delivery documents (Ghaffarianhoseini et al., 2017).

(Figure 2.3.x) shows the process of the production of tender documents, according to the requirements of Chinese building project criteria. The Quantification is based on the design documents issued by building design companies. The produced design documents are for construction purposes, and include graphical information and verbal instructions regarding specification of the fabrication and installation (Imrie, 2011). Based on those technical details given by design companies, quantification for the cost estimation and time schedule can be calculated for the reference of clients and stakeholders regarding project investment. If the project meets with the relevant expectation, then the clients will proceed to the tendering process for construction.

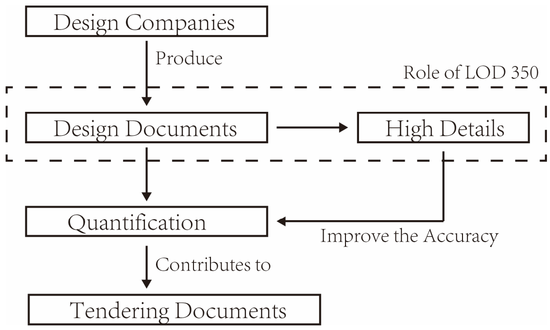


Figure 2.3 x: Production of Tender Documents

The high level of detail specification in LOD will help design companies to enhance the quality of the technical aspects of the design documents (Wood et al., 2014). Since quantification is a process to calculate the required material for construction and to estimate the schedule, increased technical detail can help to improve the accuracies of the quantification results (Rounce, 1998). The graphical and non-graphical information contained in LOD 350 contains the actual position, actual geometry, and accurate connections (Figure 2.3.x). Therefore, the design documents made by referencing the LOD 350 specification can reflect a more real situation during the construction stage for more detailed consideration during the quantification process.

In the quantification process for the cost estimation, many factors need to be considered (Elbeltagi et al., 2014). The major costs of building construction are: Labour, Material, Management Fee, Equipment, and Profits, according to documents issued by the Chinese Ministry of Housing and Urban Rural Development and Ministry of Finance (2013). The labour cost is calculated based on the number of days that a construction worker is employed, and the equipment cost is calculated based on the days that equipment is rented. Therefore, the longer the project takes, the more cost will be generated. (Figure 2.3.y) illustrates the impact of LOD 350 on the tender documents. The actual geometry impacts the quantification of the construction material, while the actual position and connection impacts the estimation of the construction schedule. Therefore, the cost estimation of the construction can be improved.

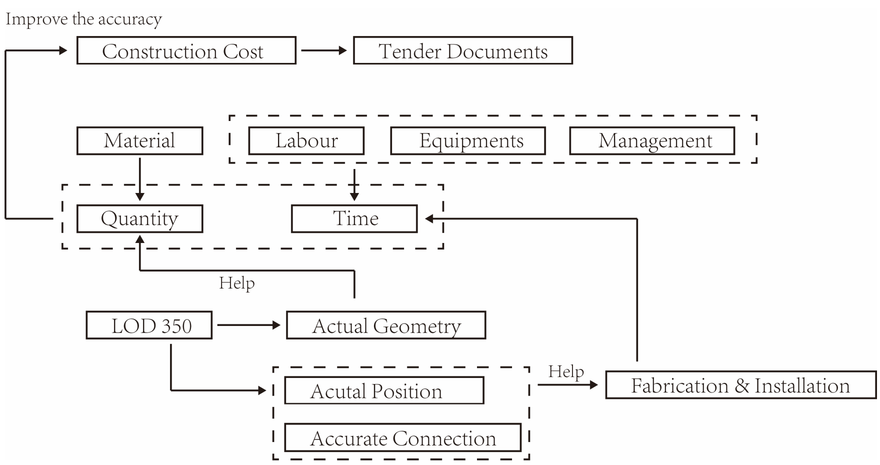


Figure 2.3 y: Contribution of LOD 350 to Tender Documents

The adoption of LOD 350 can reduce the uncertainties regarding material cost and total construction days because this high level of detail can help to calculate accurate quantities of materials and contribute to estimating total construction time. Moreover, the adoption of LOD 350 during the design stage can offer more details for the development of LOD 400 in the later construction stages due to LOD 350 helping to avoid spatial clashes from the LOD 300. Since developing a model into LOD 400 requires significant effort, the problems fixed in LOD 350 from LOD 300 can help to reduce optimization efforts during LOD 400 development. Thus, the construction team can better utilize the information in the tendering documents to make their own quantification for cost estimation for deciding whether to enter the bidding stage.

Developing a BIM model to LOD 350 level requires a lot of effort and requires the coordination of multiple modelling tools to fully integrate different building elements. However, according to literature reviews, few studies have examined the data coordination process at each LOD level, and no research has analysed how data in LOD 350 can be coordinated to increase design management. Although there are BIM modelling tools in the AEC market, it is unclear how to efficiently conduct data coordination in LOD 350 through the appropriate workflow. It is unclear what type of data and how these data need to be exchanged through the integration process to fully develop the BIM model to LOD 350 level. Moreover, efficient design assessment is demanded to use this level of BIM model due to the considerable time devoted to modelling. Hence, the findings need to be further studied through primary data analysis to test if LOD 350 can efficiently impact building data coordination.

The BIM model provides a visualized method of building project development (Eastman et al., 2011). The integrated building data in LOD 350 needs to be presented in a visualized way for project evaluation. The findings from preliminarily research have shown that the gamificative environment can potentially contribute to people's understanding in project evaluation. However, according to the literature reviews, it is unclear how integrated coordinated design data from the BIM model at LOD 350 level can be used in gamificative design visualization to improve the design management. As a result, the integration between the BIM model and gamificative environment needs to be further assessed to validate that design management can be improved through the intervention of LOD 350.

This research identifies that LOD can help the design team to build the suitable building information during each design stage and to establish a well-coordinated BIM model. LOD 350 can increase spatial coordination during design development and the adoption of LOD 350 can positively impact further BIM implementation to achieve demanding outcomes. The value of LOD 350 in design visualization is in its accumulative information and actual geometries. Furthermore, LOD 350 has effectively provided the guidance for developing the solutions in a gamificative environment, which shows its core value in the design management. BIM model at LOD 350 level can contribute to comprehensive data coordination, which can lead to efficient data analysis and data visualization, The adoption up to LOD 350 level for design development through BIM implementation can help design teams to effectively coordinate the required information. Suitable BIM implementation needs to develop the model into sufficient detail level for supporting different design evaluation purposes, which shows the value of LOD 350 on providing reference to accumulate valid building information.

There is potential impact of LOD 350 on design coordination through secondary data analysis in literature reviews. However, it is unclear how LOD 350 can enhance design business performance through improved design management. According to literature reviews, there are few studies to explore the relation between LOD adoption and business operation, and no research has analysed the impact of LOD 350 on the building design business. Although the adoption of LOD 350 can potentially improve data coordination during the design process, no research has scientifically examined the specific solutions. Therefore, there is a demand to fill this gap to validate the impact of LOD 350 on building design business operation.

Table 2.3 g: Impact of Features of LOD 350

LOD 350	Precision	Positions	Interrelations
Communication	√	√	√
Collaboration			√
Details	√		

The impact of three core features from LOD 350 is listed in (Table 2.3.g). Precision is a result of communication during detail development to ensure all the building elements for coordination are appropriately developed. The Position of building components is addressed by communication to ensure all the building components are in the right location. The interrelation occurs during communication while the collaboration process ensures the adjacent building elements are correctly coordinated. The findings are showing LOD 350 mostly impacts communication during information coordination.

2.3.5 Design Information Evaluation and Delivery

Building design projects require careful inspection and review once the production and integration process is completed (Czmoch & Pękala, 2014). Inspection is not limited to spatial clearance, but also needs to focus on the functional perspectives (Oh et al., 2015). Any potential errors and uncertainties need to be deliberately checked to minimize risk during the later stages. This research explores through experiments detailed in Chapter 4 how through the immersive visualization process, assessment for project design can be significantly improved. The role of the design management team is to ensure that inspections meet with relevant regulations and process for guaranteeing the qualitative and quantitative design evaluation (Holly et al., 2021).

Evaluation from the design stage can detect potential errors during construction development (Eynon, 2013). Following each stage of the design development, the design content needs to be inspected for quality assurance before proceeding to the next stage. Many errors have likely occurred during the design process which negatively impact another discipline during the coordination process (Juszczyk et al., 2016). Therefore, the role of design management is to ensure all design documents are correctively checked before the integration and coordination process (Elmualim & Gilder, 2014). These inspections include whether the design meets the client’s functional requirement, the building codes, and the technical standards (Imrie, 2011).

Assessment at the design stage can reduce uncertainties in the building project (Tauriainen et al., 2016) although, due to the complex nature of the building itself, uncertainties remain even after careful design inspections. Unforeseen issues cause potential risk during construction and usage of the building (Uusitalo et al., 2018). The role of design management is also to detect hidden uncertainties to minimize errors (Taylor, 2000). This research has validated that through the immersive gamificative environment, the design management team can increase capabilities to detect the uncertainties in design projects and enable prompt action to fix issues.

Investigation at the design stage can minimize the possibility of modification requests (V. Singh et al., 2011). Modification commonly occurs during the design development process (Rounce, 1998). According to the research findings, frequent modification requests are caused by lack of understanding of the project design, which will cause a request to change the building’s functional space and other relevant issues (Sanches et al., 2017). Another reason for design modification is technical issues such as spatial clashes during the construction stage, or insufficient spatial clearance (Laing et al., 2014). The role of design management is to identity those potential issues before each stage of design delivery to avoid any design modification (Knotten et al., 2017). The conceptual framework and the technical solutions proposed by this solution have validated the importance of design management in this area.

Design documents needs to be delivered to clients and relevant stakeholders for different purposes, such as design review, quality inspections, and quantifications (Knotten et al., 2015). The difference between design delivery and data transmission is that design delivery needs to be delivered as a holistic item, according to the regulations in ISO 19650. The information needs to be accepted or rejected as a whole (ISO, 2018a) and therefore, the design management team needs to ensure each part of the information is correctly produced and coordinated before delivery to the relevant parties for construction (Figure 2.3.z). This is highlighting three items during the design delivery process: quality, schedule, and media.

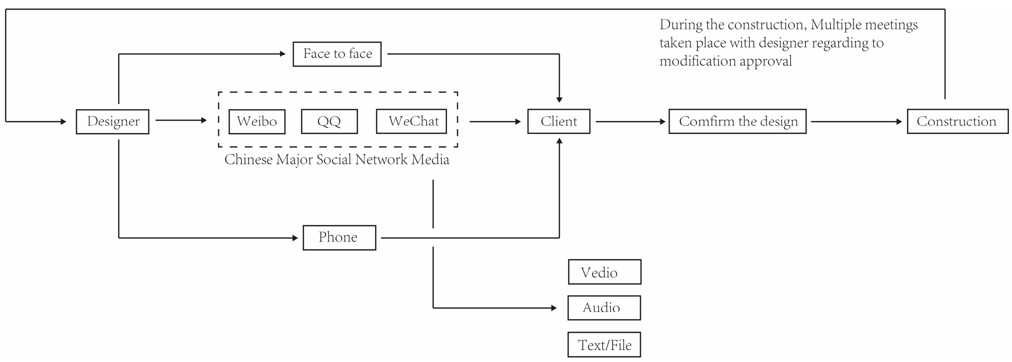


Figure 2.3 z: Process between Design Team and Clients

As identified, the building design needs to be confirmed by clients as satisfying requirements (Eynon, 2013). Normally there are three ways to establish communication with clients and stakeholders, which are, face to face meeting, social media, and phone (Figure 2.3.z). The advantage of using social media is that it can deliver the design content through different files without arranging a physical meeting. Through social media, the meeting can be held in a virtual environment, including both audio and video, which has potential capabilities to increase the decision-making process. Once the design content is confirmed, and once all the processes and paperwork are completed, the next stage is entering into construction development.

From the client and stakeholder perspective, delivery of design documents needs to be high quality. Construction is highly dependent on the delivered design documents as they provide all the technical details for fabrication and installation purposes (Arayici et al., 2011a). Therefore, the design management team needs to ensure that the design documents meet all relevant criteria before handing to the construction team, in order to avoid any problems (Rounce, 1998). Hence, the quality of design documents is considered a priority during project development.

Delivery processes need to comply with schedule expectations (Moon, Dawood, & Kang, 2014), including at the design stage of the building project (Eynon, 2013). The delivery of design documents is not only required for the quality but also for meeting the relevant schedule (Knotten et al., 2015). Since many contracts indicate that delay will incur penalty fees, the design management team needs to ensure all design tasks can be produced on time. Furthermore, the efficiencies of design delivery can allow the design team to conduct the relevant building evaluations and assessments, thus, improving the design qualities (Czmoch & Pękala, 2014).

Delivery of the building design in an understandable document form can contribute to the success of the project in the later stages (Hattab & Hamzeh, 2016). The building design documents are used for many purposes for the project, such as, construction, quantification, and facilities management (Czmoch & Pękala, 2014). According to the literature review, many issues are caused by lack of understanding of the building design due to abstract or unclear design documents (R. Laing et al., 2014). Therefore, this research has proposed a framework to increase the clarity of the design delivery through adoption of various visualized technologies. The role of design management is to efficiently handle these technologies and ensure that they are being used in an appropriate way to satisfy the relevant demands (Oh et al., 2015). This research has validated the importance of visualization technologies and highlights the role of design management during the coordination process.

The quality of building design is highly dependent on design coordination among different disciplines (Porter et al., 2015). The previous section explored the importance of spatial coordination during design management. According to literature reviews, despite the existing information management theories, lean project management framework, and gamification environment methods, there is a lack of solutions for efficient coordination of design information. As observed through personal industrial experience in building design companies, the current implementation of AEC technologies is relatively scattered, with no consistently applied strategy. The adoption of fragmented technology has little contribution in terms of long-term development (Arayici et al., 2011b). Moreover, it is even harmful (Succar & Kassem, 2015).

Building design is a professional engineering project which needs to comply with the relevant planning and building codes (Knotten et al., 2017). The Ministry of Urban and Ural Planning of China regulates the design document at each design stage. Thus, information management needs to be executed to satisfy this requirement. However, it is unclear what types of information are significant in avoiding potential design errors. With the increasing complexity of building projects nowadays (Czmoch & Pękala, 2014), clear guidance is urgently needed during the design process.

The gamificative environment proposed to conduct design visualization can help to better assess the building project according to the findings in previous sections. By adopting ISO 19650, information management can help the design team to coordinate and organize design data (ISO, 2018a). However, according to personal industry experience, many people are unfamiliar with this working environment. Jung and Joo (2011) have proposed a solution for improving those uncertainties through computer-integrated perspectives. However, it is unclear what levels of information need to be inputted into a virtual model to provide sufficient detail for effective visualization. Traditional design regulations require certain symbols to represent each of the design elements, but this is not useful in 3D-based design development. Therefore, it is necessary to validate an efficient referential to fully conduct spatial coordination.

2.4 Integrating Design Team, Design Process and Technologies

2.4.1 Situated Cognition and Gamification

Situated Cognition is a learning method from a real scenario for improving understanding (Elsbach et al., 2005). The successful accomplishment of tasks based on a scenario helps people to acquire a certain experience for succeeding in the job (Choi & Hannafin, 1995). The immersive and interactive environment will help the learner to increase the acquisition of knowledge (Baudin et al., 2021), which can enable the generation of skills, since the human conscious needs input from the surrounding environment (Clancey, 1997). In section 2.4, this research has gone through the current application of BIM paradigm to improve information coordination in building design, and the research has shown that there is a limitation within the current SMPs. With the nature of project complexity, decision-making is difficult due to abstract content. Christakis and Fowler (2013) studied how people make decisions in different situations and highlighted the importance of data recognition.

Therefore, there is a need to help people in building design development generate enough understanding in a plausible way to improve the decision-making process. Welbourne (2001) has argued that learning of certain knowledge needs to happen in a collaborative way. Building design is a complicated process which requires significant cooperation among different participants (Best, 2006). To make this collaboration efficient, the situated cognition concept will help people in further identification (Hopp, 2011), while the technical approach regarding the learning environment supports knowledge acquirement (Welbourne, 2001). Therefore, an appropriate solution needs to be found in the scenario of building design.

Integration of real and virtual environments has been studied in recent years. According to Brown et al. (1989), a realistic environment can improve the understanding of certain scenarios, thus leading to successful learning outcomes. Performance in the design process can potentially improve by using a more visualized way to integrate data and information. Ackoff (1989) introduced a Data, Information, Knowledge, and Wisdom (DIKW) theory, which can be practiced in the design process through the combination of realistic environments. The interaction between human and virtual models can increase the understanding of complex objects (Bosch et al., 2019). Slavin (2018) studied the business model and first introduced the term “Gamification”. Game itself provides a platform and environment for people to interact in a virtual context (Kocadere & Çaglar, 2018). Through the game, people enjoy themselves in a virtual environment with instant feedback (Toda et al., 2019). Thus, through the combination of gamification and the virtual environment, a gamificative environment is created for building design development, leading to improved design management performance.

Building design usually integrates multiple disciplines with the complexity of design context (Oh et al., 2015). Although design teams all belong to the AEC sector, the work done by one discipline is often difficult to understand by another discipline, especially in extreme situations during the integration process. In spite of 3D modelling tools to transform design from 2D diagrams, the interaction with design is not sufficient for generating enough contact between people and virtual environment (Mabrook & Singer, 2019). Visualization in project management can help people to understand the relevant content in the appropriate way (Koskela et al., 2018). The limitations found in section 2.4 show there is lack of interaction during current BIM implementation and therefore, despite improved spatial coordination, it is still hard to make decisions during the evaluation process. Although situated cognition is a teaching and learning method (Choi & Hannafin, 1995), this research borrows its core value to be used during interactive implementation for improving the understanding of project participants during design development.

Gamification is the business phase that applies a game solution in a non-game situation, according to the definition in academia and industry (Deterding, 2012). The purpose of the of gamification used in this context is to increase the interest of people toward certain objects (Hamari et al., 2014). This can lead to improved engagement in carrying out tasks because its core aspect is to increase motivation. Gamification has three advantages, which are: Immersive Experience, Clear Feedback, and Sharable Technologies (Dale, 2014). These advantages suit the situated cognition demands identified because the experience can enable users to immerse themselves in a scenario through the virtual environment (Seaborn & Fels, 2015), feedback from the environment can be used to make further improvement regarding insufficiencies (Basten, 2017), and the sharable techniques can highly impact interactivity for increasing communication.

The role of the gamificative environment to detect potential errors, to reduce project uncertainties, and to minimize modification frequency during project development have been reviewed. The literature review finds that the immersive and interactive technologies can increase the coordination of building components for spatial clearance and functional assessment during the evaluation process. These evaluation processes require the involvement of sufficient management for ensuring the quality of design is being deliberately checked. Building design evaluation process needs an effective model which contains the right geometric information for spatial analysis. The spatial analyses include the area calculation, clear height analysis, and activities estimation.

The Gamificative environment relies on the support of relevant technologies, and the adoption of technologies rely on SMPs from ISO 19650. According to the findings, the technologies are categorized into modelling technology, visualization technology, and interaction technology. The modelling technology under the guidance of LOD 350 contributes to the scene of the gamificative environment, which is visualized by VR, MR, and Panorama. The indoor positioning technology contributes to the interaction between people and the virtual environment. Therefore, from the bottom up, business operation performance can be enhanced.

For the review of studies and research on gamificative technologies, this research focuses on interactive and immersive solutions in BIM implementation for visualization. BIM implementation enables design teams and client teams to better understand the building project through efficient visualization. Three solutions are found to increase efficiencies of BIM implementation: BIM implementation plan, modelling guidance, and visualization strategy. The findings of literature reviews to increase information coordination are: to use appropriate standards, methods, and procedures through integration of people, process, and technologies via an interactive and immersive visualization environment. BIM models have high capabilities to conduct different tasks along the building life cycle, and the level of development plays a crucial role due to the requirement of different information for meeting project satisfaction.

Gamification is abstract; its implementation does not involve any actual game development but borrows those valuable points from game design to improve task performance (Claesson, 2017). The core purpose in gamifying a certain object is to increase its attractiveness, it does not necessarily need to be on the User Interface (UI) to be vivid enough, but to ensure that the entire process becomes suitably motivating. Another key aspect of gamification is to make boring tasks more enjoyable, hence improving task performance (Dale, 2014).

Chou (2016) has argued that gamification can increase the interest of people and impact working efficiencies. Although most of these aspects are used to develop an attractive game, some of the core ideas are worthy enough for improving the learning outcome with situated cognition. Kim (2012) highlights the four aspects of interaction, which are express, compete, explore, and collaborate. Thus, people can be linked to each other during the adoption of gamification. The key to gamification is to lead the user step by step to finalize the job through a visualized and interactive environment (Zichermann & Cunningham, 2011).

The research discovered four sectors of interaction in task development. The four main tasks in most scenarios focus on view, work, feedback, and deliver. This research has linked them, based on the findings in literature reviews. The view is a way to explore (Table 2.4.a), work is a way to compete, feedback is a way to express, and deliver requires a collaborative process. Therefore, interaction between gamification and task development can be established. The view of the environment enables people to explore, work in the environment enables people to compete, feedback enables people to express an opinion, and deliver enables people to collaborate for completing tasks.

Table 2.4 a: Interrelations in Gamification

	Express	Compete	Explore	Collaborate
View			√	
Work		√		
Feedback	√			
Deliver				√

Through research from academia, the concept of gamification has been widely investigated in terms of roles and functions. Dale (2014) states that individual and enterprise behaviour can be improved through gamification due to increased encouragement. The common agreement in research highlights that both real and virtual behaviour can be influenced through the adoption of gamification (Dale, 2014; Deterding et al., 2011; Seaborn & Fels, 2015). People are motivated to respond to certain scenarios during the game experience (Dale, 2014). Zichermann and Cunningham (2011) argue that problem solving capabilities can be improved in the game environment because it motivates thought processes. A systematic review by Hamari et al. (2014) shows that gamification has been successfully implemented in many companies during their business operation. Therefore, the concept of gamification has the potential to impact the business operation of building design companies because the gamification approach can motivate people to solve problems.

Gamification normally has a visualized environment for conducting the interaction between people and virtual objects. The visualized environment is established in one of two ways; one way is a pre-built environment as per most game designs, and the other is an environment built by players, such as SimCity or Minecraft. The immersive and visualized virtual environment increases attraction, which can increase engagement between end-users and game platform. The method of building the virtual environment itself is a fun process, which can lead end-users to accomplish tasks in a pleasant way. The visualized information through the gamificative environment helps end-users to understand the relation between each virtual object, which speeds up the task process. (Table 2.4.b) shows the interrelations in a Gamificative Environment. The visualized data can increase motivation and attraction, the accumulated data can increase motivation and engagement, while data interaction can increase engagement and attraction, according to the findings from literature reviews.

Table 2.4 b: Interrelations in a Gamificative Environment

	Motivation	Engagement	Attraction
Visualized	√		√
Accumulated	√	√	
Interacted		√	√

Based on the above identified aspects of gamification, the research has found that this approach can be used in processing the information for improved efficiencies. Information processing and development are very boring tasks in most scenarios, and people easily tire during the process. The motivation and engagement brought about by gamification can increase their interest in the task in different working environments (Claesson, 2017). As most data are usually not visualized, the way gamification works can change those non-graphical data into graphical content for aiding in cognitive understanding (Basten, 2017). However, the entire process of gamification is technical, since the visualization and interaction rely heavily on support from various technologies (Díaz et al., 2019). Moreover, the technical development of gamification relies on efficient coordination between people and process. Therefore, it refers to the heart of the BIM paradigm, which is people, process, and technologies, to determine the successfulness of a project.

Gamification in building design is being developed for improving information coordination during design development through increasing the engagement between design team and digital model. The engagement is mostly through the interaction of people and graphical model; therefore, a gamificative environment for visualizing the design data is required for the whole process. As identified, visualization in building design is not simply presenting the graphical context, rather it requires a way to interact with the design outputs. Therefore, a visualized gamification environment needs to consider how the end user can easily review the design context.

Motivation is another factor which is important during the implementation of a gamificative environment. Since dealing with large amounts of design data will easily cause boredom, to maintain the user's interest during a task is an important element. Therefore, the gamificative environment needs to be attractive enough to increase the willingness of people to engage. Information coordination in building design consists of three stages: design planning, design production, and design evaluation (Table 2.4.c). According to the findings, based on the features of gamification, this research has identified the following relations, listed in the (Table 2.4.c):

Table 2.4 c: Interrelation Between Gamification and Design Development

	Design Planning	Design Production	Design Evaluation
Attraction			√
Motivation		√	
Engagement	√	√	√

The impact of gamification on building design coordination is in providing a comprehensive environment for immersive visualization and interaction with support from different relevant technologies. Through the feature of attraction, motivation, and engagement, project teams can conduct better communication and feedback for enhancing the design evaluation, hence improving decision making. This research has identified gamification as an attractive platform for people to interactively review data for improving the collaboration process, thus increasing the performance of building design business operation.

Therefore, according to the findings in the literature review, the following can be stated:

- A Gamificative environment can improve the interaction between people and virtual environment during the building design process.
- A Gamificative environment can help to improve the immersive and dynamic experience during the building design visualization process.
- A Gamificative environment can enhance the involvement of project

participants toward the design.

The three aspects focus on Interactivities, Immersive, and Involvement and can be linked together to impact the building design process for contributing to information coordination. Hence, the solution to enhance the building design business operation is that information coordination can use the concept of Gamification to improve collaboration, improving business performance and collaboration capability.

Table 2.4 d: Impact of Features of Gamification

Gamification	Attractions	Motivations	Engagement
Communication		√	√
Collaboration	√	√	√
Details			√

The impact of three core features of gamification on information coordination has been identified from the literature review findings. (Table 2.4.d) shows attraction from gamification is interrelated with collaboration and details to ensure all the project participants are willing to be involved. Motivation is interrelated with communication and collaboration because once people are motivated, they are more willing to communicate with other team members during the collaboration process. Similarly, once people are engaged in the virtual environment, their communication and collaboration will improve. Therefore, gamification mostly impacts the collaboration process during information coordination.

This research argues that gamification is an approach regarding task accomplishment in situated cognition. Features and characteristics in gamification can improve the learning outcome through the visualized and interactive environment (Friedrich et al., 2020), which meet the criteria of situated cognition to increase understanding (Elsbach et al., 2005). According to the findings of this research, gamification is a way of implementing BIM. The identified limitations of BIM can be filled through the technical development of visualization and interactions. The integration of demand and technical solution can be used to improve information coordination (Arayici et al., 2011b). Section 2.4.2 and Section 2.4.3 explore different visualization and interaction environment and technologies in the AEC market.

2.4.2 Immersive and Interactive Digital Environment

The research question is to find whether and how information coordination in building design can be impacted by an interactive and immersive gamificative environment, and this research is arguing that gamificative environment can improve people's understandings toward a project to support decision-making. Through the comprehensive exploration of theories, standards, and precedent studies, this research has confirmed the potential impacts from interactive and immersive technologies on building projects.

In fact, the role of the immersive environment can improve the understanding of people toward project development. Immersive solutions such as wearable headsets can help end-users to establish a better understanding toward a project via an immersive virtual environment to support the design review and evaluation process (Cha et al., 2019). Wearable headsets enable end-users to have immersive visualization toward digital content; therefore, understanding of the project can be improved for enhancing the efficiencies of professional management (Arantes & Irizarry, 2017). Virtual Reality technologies allow people to visualize in a real scale environment, which could allow participants to have immersive perceptions to increase understanding (Hugo et al., 2022).

Beyond the design stage, the immersive environment has more capabilities during the project life-cycle. During the post occupancy management and evaluation, immersive technology can impact on the study of relevant behaviours because it can offer a realistic environment to provide reference (Zhu et al., 2018). Immersive technology can impact on the sustainability of an architecture project, because it can provide a way to merge the physical and virtual worlds (Suryawinata, 2021). Moreover, immersive technology can be integrated with other technology to be more functional. For example, it can be integrated with UAV to impact project understanding during the construction stage (Faris et al., 2021). Immersive technology will also help people to efficiently identify key areas (Bjørn et al., 2021). The immersive environment relies on the development of detail; therefore, the involvement of Level of Development (LOD) can support end-users to have better a perception toward a project's physical details in a virtual environment, which can enhance relevant decision-making performance (Abouelkhier et al., 2021).

Awareness of the interaction between human and architecture design through computers to improve project performance has increased over recent years (Alavi et al., 2019). The involvement of interactive technologies enables people to better explore the virtual environment. The visualization of a BIM model can be integrated with Virtual Reality, Augmented Reality, and Mixed Reality to improve the sustainability of project development (Khan et al., 2021). Augmented Reality can fill the gap between design and construction by providing a clear reference to enhance the accuracies in fabrication and installation (Fazel, 2018). 3D visualization can enhance people's understandings towards a project as perceptions can be increased to support relevant decision-making (Mataloto et al., 2020). The demand to visualize 3D information in AEC industries is growing, requiring the involvement of interactive technologies during project development to improve people's engagement (Wang, 2022).

The immersive and interactive intervention in the design process can provide immediate feedback to support better collaboration, because participant understanding of a project is improved due to increased communication (Roupé et al., 2020), while production capability is increased under the Virtual Reality environment (Latini, 2021). Since a building project is usually very complex, significant efforts is required to guarantee its quality and efficiencies. The demand in interaction and immersive technologies requires the combination of different technologies during project design development (Almeida et al., 2019). The involvement of different technology can help to develop a project in a positive way; for instance, an interior design project can be impacted by interactive and immersive visualization technology since a more realistic environment can support participants' understanding of furniture allocation (Prabhakaran et al., 2021). Moreover, interactive technologies can increase collaboration. A study conducted by Tayeh and Issa (2020) shows that interactive technologies such as holograms can increase communication among different participants (Tayeh & Issa, 2020).

The direction of future research on Virtual Reality needs to focus on how its realism and immersiveness can be improved, and technical intervention needs to focus more on end-user experience (Kalantari, 2020). Interactive technologies are not affecting the direction of project design; however, further research needs to focus on how tools can be developed to improve project performance (Brown, 2020). Technology adoption needs to focus more on people, as end-user experience is very important during interactive and immersive interventions (Li et al., 2020).

A Gamificative environment in building design depends on visualization (Petridis and Traczykowski, 2021), hence it is the environment defined by this research for holding content for interaction. A gamificative environment has three approaches, according to the findings of this research, which are: graphical content to support visualization, technologies to support interaction between the real and virtual world, and information container to store the data and share the communications. The interaction is based on the visualized environment, and the visualized environment is based on the development of data. On this basis, this section discusses how to integrate existing AEC technologies to build a visualized and interactive gamificative environment to support information coordination.

According to current technologies, there are two ways to visualize data: static images and videos. Static images are widely used in many fields as a form of chat diagram and mapping. Videos are a form of stacking multiple images in a continuous way to show the motion of an object. Images and videos are frequently used in many areas such as a medium of presentation and discussion. Although data are vividly visualized, due to the large content and complexities of information in AEC industries, especially in the field of building design, this content cannot satisfy the increasing demand for conducting information coordination. Therefore, more data visualization techniques are demanded.

Building design information coordination can be improved through increased interactivity in a well-developed immersive visualization environment, because in such an environment, data can be commonly shared in an accessible way for improving peoples' understanding of building design, which enables efficient evaluation and assessment for decision making with the support of relevant IT technologies.

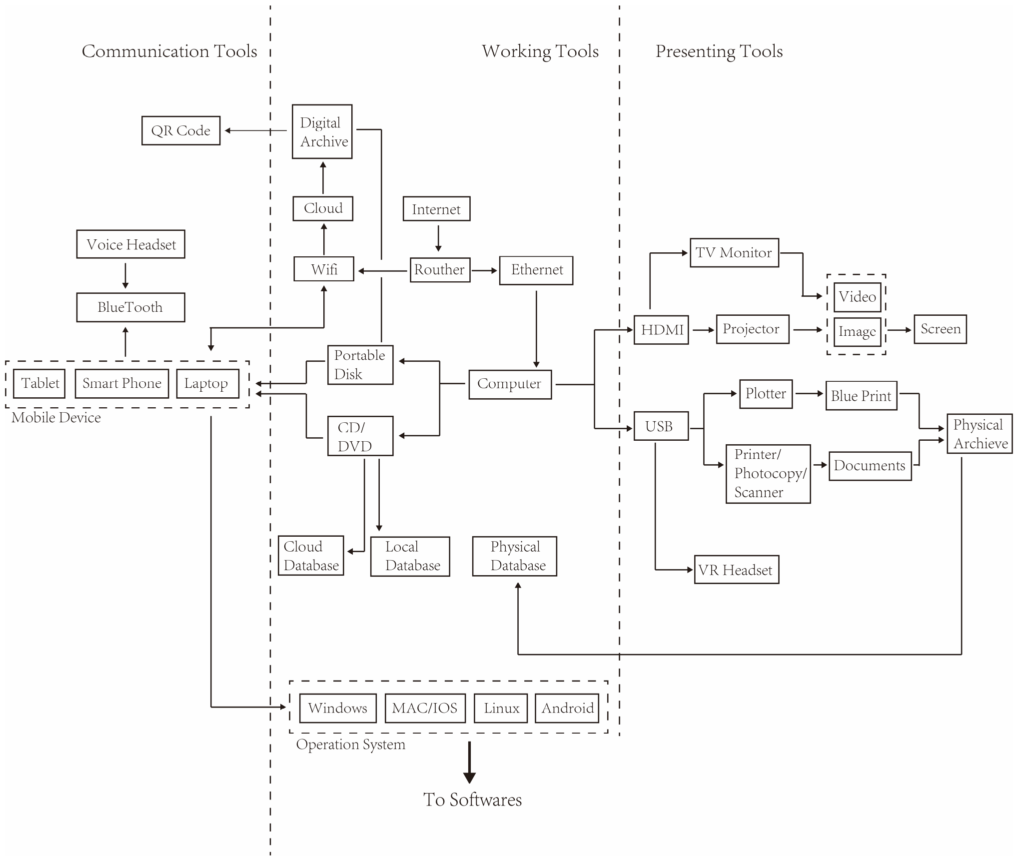


Figure 2.4 a: System Architecture for Immersive Technologies

Data need to be integrated and coordinated through different production technologies and tools before entering visualization and immersive interaction. The integration of technologies consists of IT mobilization, which comprises numerous hardware and devices (Figure 2.4.a). Most building design data are produced on a desktop via professional design software. To enable these data to be visualized and presented, multiple devices are used for data exchange between different systems. The exchange of these data includes both wireless and wired devices. The entire process highlights the importance of data exchangeabilities during the coordination of building design information.

This research has explored state-of-the-art visualization technologies from three areas: immersive, dynamic, and interactive. According to Merrian-Webster (n.d.), the definition of immersive is, “providing, involving, or characterized by deep absorption or immersion in something." This highlights the character of in-depth involvement of doing a certain thing. The feature of traditional visualization methods is not defined as immersive because it lacks sufficient depth in presenting the data. To reach the immersive level (Nussipova et al., 2019), more involvement between digital assets and people needs to be established. The definition of dynamic and interactive is very clear: dealing with activities between people and objects. Since the research has found that immersive needs to focus on sufficient involvement between people and data, dynamic and interactive are the premise to create an immersive environment for visualizing building design data.

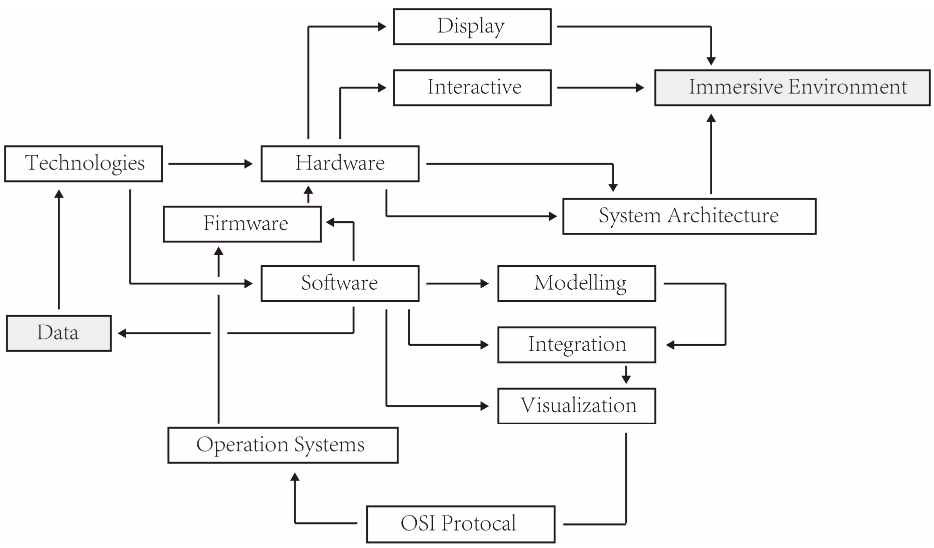


Figure 2.4 b: Structure for Immersive Environment

(Figure 2.4.b) shows the findings from the exploration of technical solutions for building system architecture for an immersive environment. The establishment of an immersive environment requires the combination of different software and hardware with the support of an OSI protocol to link different operating systems. The established framework data from building design development can interact through the virtual environment for increasing its coordination.

Once visualized, the project team needs to deal with the data for the purpose of information coordination. Based on the literature review, this research has found that using gamificative technologies can potentially impact the performance of design coordination. The technologies used during gamification are categorized as visualization and interaction (Figure 2.4.c) and, through their implementation, the gamificative environment can be established for coordinating building design information. Hence, this research has found that through the adoption of CDE, three processes of data development can be addressed prior to information coordination, which are: access the data, visualize the data, and deal with the data. A Gamificative environment is proposed to improve the collaboration process.

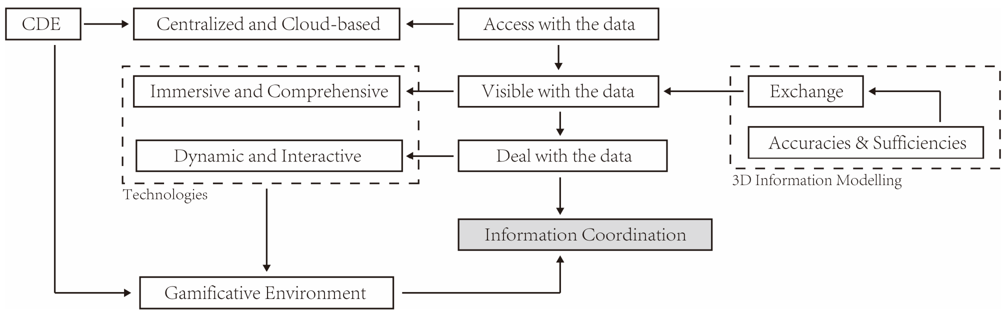


Figure 2.4 c: Findings of Impact of CDE According to the Literature Review

Therefore, this research has identified that collaboration is weighted as the most important aspect in the coordination of building design information. As found through the literature review, Common Data Environment (CDE) is the key platform for carrying building design information during the collaboration process, because it provides an efficient way for project participants to conveniently access data regardless of the location and operating system. (Figure 2.4.c) shows the impact of CDE on building design data for increasing information coordination. The role of CDE is to centralize data from the cloud-based platform for increasing accessibility. Once the data are accessed, they need to be visualized through an immersive and comprehensive experience. Before visualizing the data, the 3D information model needs to be effectively exchanged and coordinated for considering data accuracies and sufficiency.

2.4.3 Immersive and Interactive Digital Technologies

As regards the definition and understanding of immersive, this research proposes three visualization techniques, which are Virtual Reality (VR), Mixed Reality (MR), and Panoramas. VR technologies are technical solutions to simulate the real-world environment through a wearable headset, enabling the user to experience virtual content. Since 2016, VR has become increasingly popular, with many manufacturers launching VR devices and applications. The core characteristic of VR technologies provides an immersive and interactive visualization experience for users to be involved in-depth in the virtual environment, for both entertainment and working purposes. The further development of VR technologies enables the arrival of Mixed Reality. The major difference between MR and VR is that in MR allows the input of information rather than merely watching the existing information, which improves the interaction between the real and virtual world. Since the development of visualization and interaction technologies, the boundary between MR and VR is narrowing, as it becomes increasingly hard to know to which category a wearable headset device belongs.

The interaction through the VR and MR environment depends on technologies called indoor-positioning technologies. There are two major types, known as Inside-out and Outside-in. These two different positioning approaches enable precise location in the virtual environment, which can subsequently be used for tracking the motion of people. The technique of Outside-in uses a sensor to cut Infra-red, while the location can be computed through the combination of multiple sensors. These sensors are distributed along wearable headsets and hand controllers; therefore, the motion capture of this technique is relying on the external equipment. An example of a wearable VR headset using Outside-in technology is HTC Vive Pro, which consists of two to four positioning trackers, one headset, and two hand controllers.

Despite the accuracy of positioning made by this technique, the number of devices required is inconvenient, and due to the external devices, there are a limited number of interactive spaces for the immersive environment (e.g., the maximum trackable space in HTC Vive Pro is 10 meters by 10 meters). (Figure 2.4.d) shows the interrelation between different hardware of the Outside-in positioning technology by using HTC Vice Pro. All motions are captured by tracker, sent back to a PC for computation, and presented in class for immersive and interactive visualization.

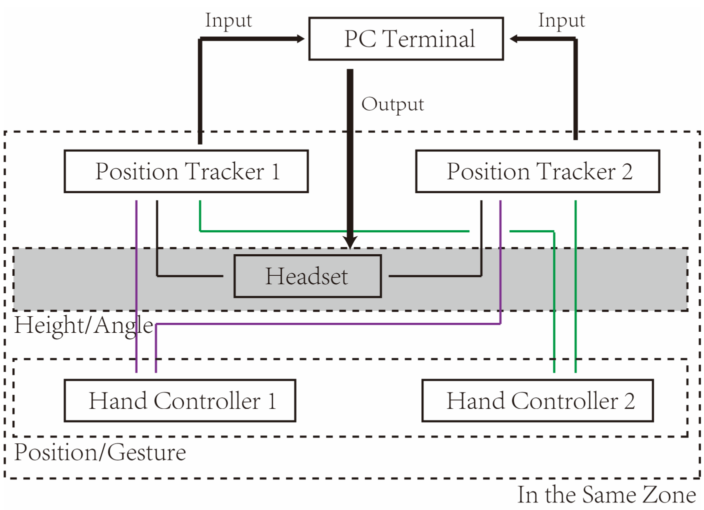


Figure 2.4 d: Outside-in Positioning System

For improving limitations of Outside-in technologies, the Inside-out positioning system has been developed for reducing the dependence on external devices. One of the most widely used techniques in this category is called Simultaneous Localization and Mapping (SLAM). With this technology, the device uses a laser to configure the surrounding environment and generates the model based on the motion of the captured images. The most advanced feature of this technology is that it is less dependent on external devices, which enables freedom of movement without the limitation of box scopes. No hand controller is required with this technology since, through laser capturing, the motion of the hand is captured by laser to interact with the virtual objects. The representative wearable device using this technology is HoloLens. Unlike other wearable headsets, HoloLens does not depend on inputting data from an external computer. HoloLens itself is a micro-computer which can support multiple activities.

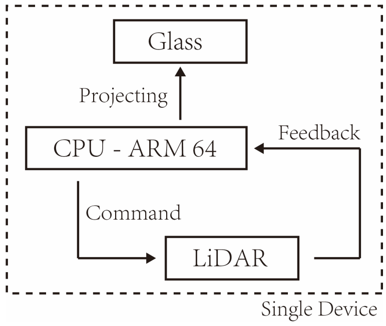


Figure 2.4 e: Inside-out Positioning

HoloLens is integrated with SoC (System on Chip), which can run the program independently, enabling the viewer more freedom of movement. It also has capacities to track the viewer's position based on its Simultaneous Localization and Mapping (SLAM) algorithm from the data collected by its integrated Light Detection and Ranging (LiDAR). Therefore, since no external position tracker is required, this enables movement beyond a restricted area and portability for conducting immersive and interactive visualization. (Figure 2.4.e) shows the system architecture of how HoloLens conducts positioning computation for visualization. All the data capturing, and computation can be completed in a single device.

The role of HoloLens has been studied at length to explore its potential impact on the interactive environment through immersive visualization. Since one of the major functions of HoloLens is to bring the real and virtual world together, virtual objects can be integrated with real objects during the design intervention. For example, design teams can overlay the digital content on the real environment to see how the design fits. Moreover, users of HoloLens can project the hologram through the MR environment and interact with the model through a series of actions such as scaling, roaming, and rotating. This provides not only an immersive environment, but also the type of interaction that increases engagement.

Panorama is another immersive technology that provides comprehensive visualization. The Panorama itself is a static image, but it presents a view in a comprehensive way, in a 2:1 image or through six cubic images. Panorama can be presented in a VR environment because the 720-degree viewpoint enables VR to be read in an immersive way, thus allowing the end user to view the environment in a wearable headset. Despite Panorama needing a holding medium like a wearable VR device, it can be lightly used through a mobile application. There are various support applications that can present Panorama images, and many social media websites have integrated these functions. For example, Facebook can read and present uploaded Panorama photos, which can be viewed through browsers and mobile apps to offer the end user a convenient way to access the data. This research has identified that Panorama's greatest advantage is its affordability since, unlike VR, which relies on expensive external equipment, Panorama can be simply viewed through daily accessible devices.

Another aspect of Panorama identified by this research is that, through the stacking multiple static images from the output of Panorama engines, a dynamic way of data presenting can be achieved to enable interaction between people and design output without the support of an indoor positioning system. This research has named this method of interaction as, "Static Images-based Dynamic Interactions." This way of presenting design data needs the support of software, and there are many available tools, such as 720Yun, which can provide an online database to hold Panorama images, enabling the end user to interact with integrated multiple images.

Since regular VR is still not sufficiently sophisticated to be used by people, causing dizziness and other problems, it is not the best way to make design presentation to clients. Although VR and MR devices can help professional design teams to increase their understanding of design content, mobile app-based Panorama is considered as the most appropriate method for client delivery. Unlike regular VR, which is mostly dependent on a local drive, online-based Panorama enables the sharing of content among different people in a very accessible way, such as Quick-Response (QR) code or simply via a URL link.

Many rendering engines can output Panorama images from a design model, such as VRay, 3D Studio Max, Enscape3d, etc. The material and texture information can be read through the rendering process to generate photo-realistic quality pictures. These Panorama images can be integrated in an organized way to deliver the design presentation. Beyond output from 3D information models, Panorama images can be captured via Panorama cameras though onsite capturing to enable the immersive experience of existing conditions. A virtual tour can be made through such technical solutions to provide an immersive experience from online access.

From the arrival of Nintendo, PlayStation, and Xbox, game development has increasingly attracted significant investment. With the wide availability of smartphones, millions of mobile games are being developed for making money. With the popularity of video games, many videos game development platforms are being launched, such as Unity and Unreal Engines, where people can easily develop their own game based on large digital asset libraries and source codes. From this aspect, it is time for building design teams to adopt the game concept to increase engagement between design team and virtual environment. However, what needs to be clarified is that gamification in building design is not making video games; it is borrowing concepts and ideas from video games to improve design information coordination.

The production of information in building design generates large amounts of data, which often places a heavy load on PCs or portable devices. Inevitably, some of the data in a single document will not be reviewed because those reading it may be focusing on a particular point of project design. Therefore, this unnecessary data does not need to be included in the review process. As a result, data can be saved as a rendition file to reduce size and minimize streaming and computing pressures. In the building design process, the 3D information model is usually very big, and this large file requires the support of a High-Performance Computer (HPC). With the reduced file, not only is the size reduced, but it allows the project team to quickly deal with the right information.

The research discusses how to improve the understanding and the engagement of people through the implementation of BIM paradigm. The philosophy of using BIM is to increase collaboration through the integration of people, process, and technologies to establish efficient information coordination for improving design delivery. The issues identified through the research can still not be effectively addressed by adopting ISO 19650 and LOD 350 because the 3D information model is not interactive enough for creating a collaborative environment. This section uses the theory of situated cognition, which uses the immersive scenario to improve the understanding of people towards a certain situation. The research then identified that gamification has the right approach to fit this theory. Through the investigating of features and characteristics of gamification, this research has found that attraction, motivation, and engagement are three key aspects that can be gained from a successful gamificative environment. The adoption of various technologies achieves interaction between people and the virtual environment, which can subsequently lead to improved decision making.

Table 2.4 e: Findings of Impacts from Interactive and Immersive Technologies

	Virtual Reality	Mixed Reality	Panorama
Visualizations	High	High	Medium
Accessibilities	Low	Low	High
Interactions	Low	High	Medium
Immersive	High	High	High

(Table 2.4.e) shows the impact of three different technical solutions to establish a gamificative environment. According to the findings, the information coordination building design depends on data visualization, data accessibilities, data interaction, and an immersive environment. From exploring each solution, it is found that there are different degrees of impact regarding the limitation of current techniques. To test the findings, this research has used three case studies to conduct the experience of these three gamification approaches.

The problem in the current stage is that, despite the existence of many advanced AEC technologies such as VR and MR which can help the coordination of building design information, it is unclear how to efficiently implement them into a practice-based building project. A conceptual framework is urgently needed to guide building design companies to efficiently allocate resources for improving building design qualities. The findings in the literature review show that the interaction between human and computer can increase the understanding of the digital environment. Situated cognition is established on the experience of the targeted objects (Dawson, 2010). The purpose of the virtual environment in building design is for people to see and assess the relevant design (Zaker & Coloma, 2018). The literature review shows that previous research has found that gamification can increase people's interest toward a certain scenario and will subsequently increase their interaction with virtual items.

2.5 Interactive Integrated and Immersive Building Design Environment

Issues identified in background study and preliminary research show that poor understanding of project design is affecting business operation because people are insufficiently confident to make decisions. Poor understanding is caused by lack of detail, insufficient collaboration, and inefficient communication. To address this issue, this research examined precedent studies in management, technologies, and codes/standards to find solutions. Findings regarding increased information coordination in building design (Table 2.5.a), shows that design detail is impacted by the integration between ISO 19650 and LOD 350, collaboration is impacted by the integration between ISO 19650 and Gamification, and communication is impacted by the integration between LOD 350 and Gamification.

Table 2.5 a: Findings from Precedent Studies

	ISO 19650	LOD 350	Gamification
ISO 19650		Design Details	Collaboration
LOD 350	Design Details		Communication
Gamification	Collaboration	Communication	

The findings show ISO 19650 and Gamification mostly impact collaboration. Since all the features of ISO 19650 and Gamification are interrelated with collaboration, this research considers that collaboration during design information coordination mostly impacts the quality of building design delivery. The findings also show that LOD 350 mostly impacts communication because the position and interrelation of building elements require mutual agreement from different disciplines. Also, the features of Gamification impact communication; therefore, communication during building design information coordination is mostly interrelated with LOD 350 and Gamification. As identified from the literature review, the role of 3D information modelling provides a foundation for the gamificative environment, and the quality of these virtual models depends on precision and accessibility. Therefore, its detail development is interrelated with features of LOD 350 and ISO 19650.

While precedent studies show that LOD 350 can increase the information development, ISO 19650 can increase information management, and Gamificative technologies can increase information visualization. However, this does still not satisfy requirements in terms of improving building design information coordination because building design is a very complex process which requires the integration of people, process, and technologies. Therefore, a new integrated solution is required that encompasses all requirements of the building design development process to improve design team productivity. The findings from precedent studies show that there is currently no particular solution in the AEC industry specifically for improving project understanding in building design.

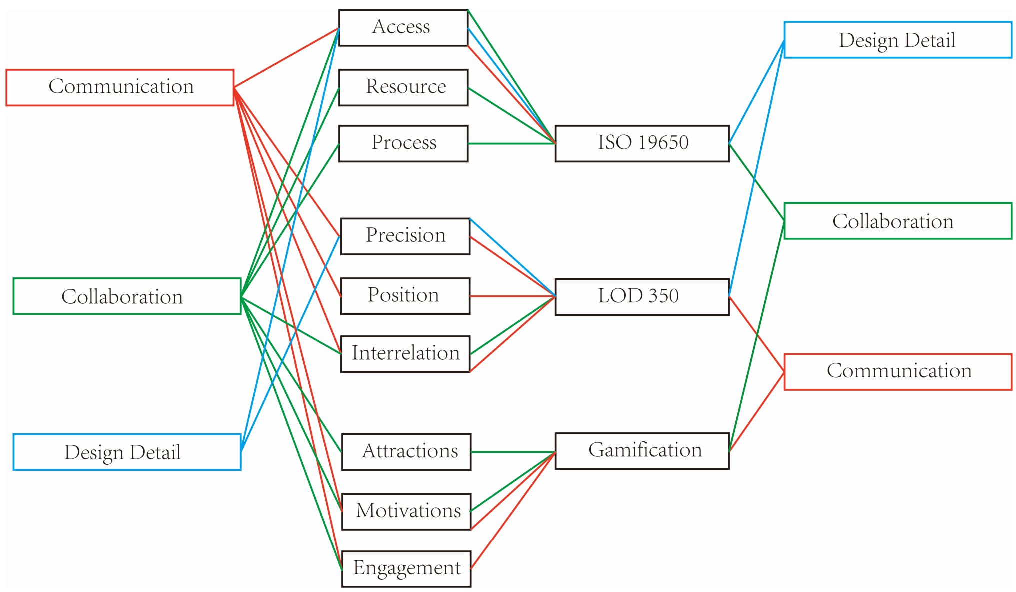


Figure 2.5 a: Interrelation Between Each Feature in the Proposition

There is a need to guide how BIM can be implemented in building design project. Hence, to fill this gap, this research integrates criteria of ISO 19650, specification of LOD 350, and technologies in Gamification to improve project understanding and increase design information management. The stand-alone involvement of LOD 350, ISO 19650, and Gamification has limited functions, while through the combination of all three (see Figure 2.5.a), a whole new solution addresses the problems in design information coordination. Therefore, based on the findings and gaps, an immersive and interactive visualized building design environment is proposed for increasing design detail, communication, and collaboration in building design development to improve design team productivity, which is named “Gamificative Environment” by this research.

2.6 Chapter Summary

In conclusion, this chapter examines the secondary data to find solutions to enhance the building design business operation. This research has found that the business operation of building design companies depends on design team production capability. Once information coordination in building design is increased, the productivity of the design team will increase. In the literature review, weak evidence is provided by the researcher’s personal industry experience. However, strong evidence is found in literature and systematic review from precedent studies, focusing on technologies, standards, and design management.

The standards are regulated by national and local government, which are already peer reviewed by top professionals and experts. Design management is from existing theories, adopted in many disciplines. The technologies in AEC industries are implemented and tested by other researchers under scientific procedures, and are so proven. Therefore, this strong evidence from literature and systematic review supports the weak evidence from the researcher’s personal industry experience to propose a new direction to increase information coordination in building design.

A proposition has been developed from the findings in Chapter 2, which is: *An interactive and immersive visualized gamificative environment through integration of people, process, and technology by using appropriate standards, methods, and procedures can improve understanding to increase information coordination for enhancing building design business operation.* The highlight of the proposition is the adoption in building design of LOD 350 to develop a 3D information model and a Gamificative Environment to coordinate the design information for enhancing its business operation.

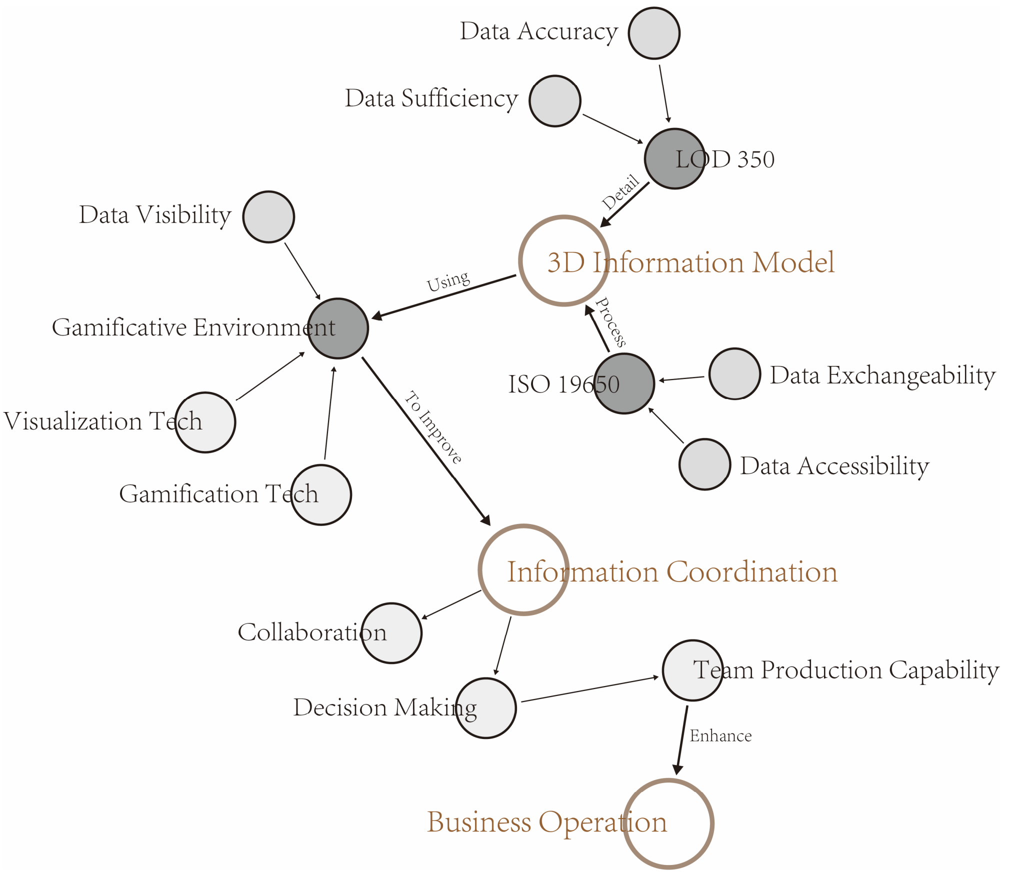


Figure 2.6 a: The Proposition to fill the Gap (1st Version Conceptual Framework)

The structure of the proposition (1st version of conceptual framework) is illustrated in (Figure 2.6.a), which shows the interrelation between different elements in building design. Five key factors of information coordination (Data

Visibility, Data Accuracy, Data Sufficiency, Data Exchangeability, and Data Accessibility) are linked with LOD 350, ISO 19650 and Gamification. This research proposes that an interactive, immersive visualized gamificative environment can help to improve project understanding and increase decision-making efficiencies for enhancing the business operation in building design.

Chapter 3: Research Methodology

3.1 Introduction

The common methods used in the gamification field are literature/systematic review, interview, case studies, and survey, according to precedent studies. Gamification, a field of social science, is an approach of adopting game elements in non-game contexts to improve motivation and participation. Mixed methods can help researchers to conduct comprehensive assessments and evaluations to measure the impact of gamification, and involve use of literature/systematic review, interview, and case studies. Alsawaier (2019) proposed a mixed method for establishing a comprehensive understanding of gamification. Tenorio et al. (2021) also used mixed method for investigating the impact of interactions on students through the gamificative approach.

Interviews can help researchers to clarify the demands and needs in gamification. Morschheuser et al. (2017) adopted the interview method, as did Loos and Crosby (2017), where it was used to identify the impact of gamification on education. Literature review and systematic review can help researchers to explore the findings from precedent studies; Zhang et al. (2021) used these methods in the field of gamification development, while Hassan and Hamari (2020) studied the impact of gamification on participation by using systematic review. Case study is commonly used to study the impact of certain elements on gamification. Andreea and Leba (2014) identified components in a specific part of gamification by the case study method, and Murugappan et al. (2018) compared the outcomes of two case scenarios by using different technologies to measure the impact of gamification.

Therefore, this research follows the criteria of gamification to study whether and how gamification can impact on building design development. Interviews and focus groups are both aimed at collecting primary qualitative data from people's perspective; interviews are more detailed while the focus group is more efficient. Action research consists of a scenario to analyse different cases in order to make a comparison; case study can conclude from a single scenario while action research needs multiple stages. Qualitative data is used to identify the specific solution to address the research gap, while quantitative data is used to validate the findings. Hence, interview, action research, and focus group are three methods used in this research to discover the impact of gamification on information coordination. A survey is conducted toward the end for validating each impact on gamification.

This research studies how information coordination in building design can be increased. Building design required the involvement of multiple disciplines, therefore, the production and coordination of building information is a process that requires collaboration. Action research studies whether a gamificative environment can increase the information coordination in building design. Due to the nature of this research field, experiments in intervention studies can only be conducted as teamwork to evaluate the impact of gamification on communication, cooperation, collaboration, and coordination during project development the experiment is meaningless if projects are conducted individually. In three intervention studies of this action research, the researcher designs the system architecture for implementing gamificative technologies, to test its theoretical and practical feasibilities. Different technological solutions are developed and implemented in different types of projects to generalize the effectiveness of gamification on information coordination, deductions are then further developed into a conceptual framework.

This research aims to enhance the quality of building design companies' business operation. The research question is how information coordination can be improved during building design development. The aim is divided into three research objectives; for each objective, different methods are used. Both qualitative and quantitative data have been collected to explore and validate the findings. The secondary data of this research is from existing literature. The primary data is from semi-structured interviews, intervention studies in action research, focus group discussions, and survey.

The research uses a progressive method to approach the outcome; the findings from each objective are used for exploration of the next objective. Through the findings from each objective, the research develops a conceptual framework for reference to improve building design information coordination. The conceptual framework is validated via the quantitative and qualitative data from the focus group discussions. Furthermore, limitations and future works are identified based on the data analysis.

3.2 Research Design

This research uses different methods for each objective (Table 3.2.a). In research objective 1, secondary qualitative data from the literature review and primary qualitative data from semi-structured interviews are used. In research objective 2, secondary qualitative data is used from systematic reviews, primary qualitative data from semi-structured interviews, and primary qualitative data from the action research. In research objective 3, primary quantitative data and qualitative data are collected from focus group discussions; qualitative data from action research are also used. The following table demonstrates the relations:

Table 3.2 a: Research Design

	Type	Methods	Data Analysis
Objective 1	Qualitative	Interviews	Clustering
Objective 2	Qualitative	Systematic and Literature Reviews	Deduction
Objective 3	Qualitative	Intervention Studies	Evaluation

	Qualitative	Focus Group Discussion	Clustering
	Quantitative	Survey	Statistic

The data sample for conducting the analysis and discussion includes literature in relevant academic areas, AEC professionals for interview and focus group discussions, survey, and real project case scenarios (Table 3.2.b). The following table shows the sample for addressing each of the objectives. For the literature review and systematic review, the sample sources are from the online database, which can be accessed through the university's NUsearch. The sample quantity for the literature review and systematic review are 617. This research has interviewed nine people from different AEC professions. Three intervention studies have been chosen for conducting the experiment and induction in action research. Thirty people from different AEC industries attended the focus group discussion, and 67 surveys were collected for quantitative analysis.

Table 3.2 b: Research Sample of Each Method

		Sample Source	Sample Quantity
Interviews	Objective 1	AEC Professionals	9
Systematic and Literature Review	Objective 2	Online Database	617
Intervention Studies	Objectives 3	Design Company's/ University's Project	3
Focus Group	Objective 3	AEC Industries	30
Survey	Objective 3	AEC Industries	67

(Figure 3.2.a) shows the progress and interrelations of this research. Chapter 1 identifies the motivation as to why information coordination needs to be improved. Following, preliminarily research is conducted to identify the factors impacting information coordination in building design development. Potential solutions are explored to address problems. Chapter 2 explores the solution from literature reviews to identify features and characteristics of LOD 350, ISO 19650 and gamification for proposing the initial conceptual framework. Chapter 4 uses case scenarios through deducting impacts of LOD 350, the gamificative environment, and ISO 19650 on design information coordination by using different gamification technologies in different types of design projects. The updated conceptual framework is proposed according to the results. Chapter 5 discusses the impact of information coordination on building design business operation through discussing the conceptual framework with AEC professionals via a focus group. The collected data is analysed for finalizing the proposed conceptual framework.

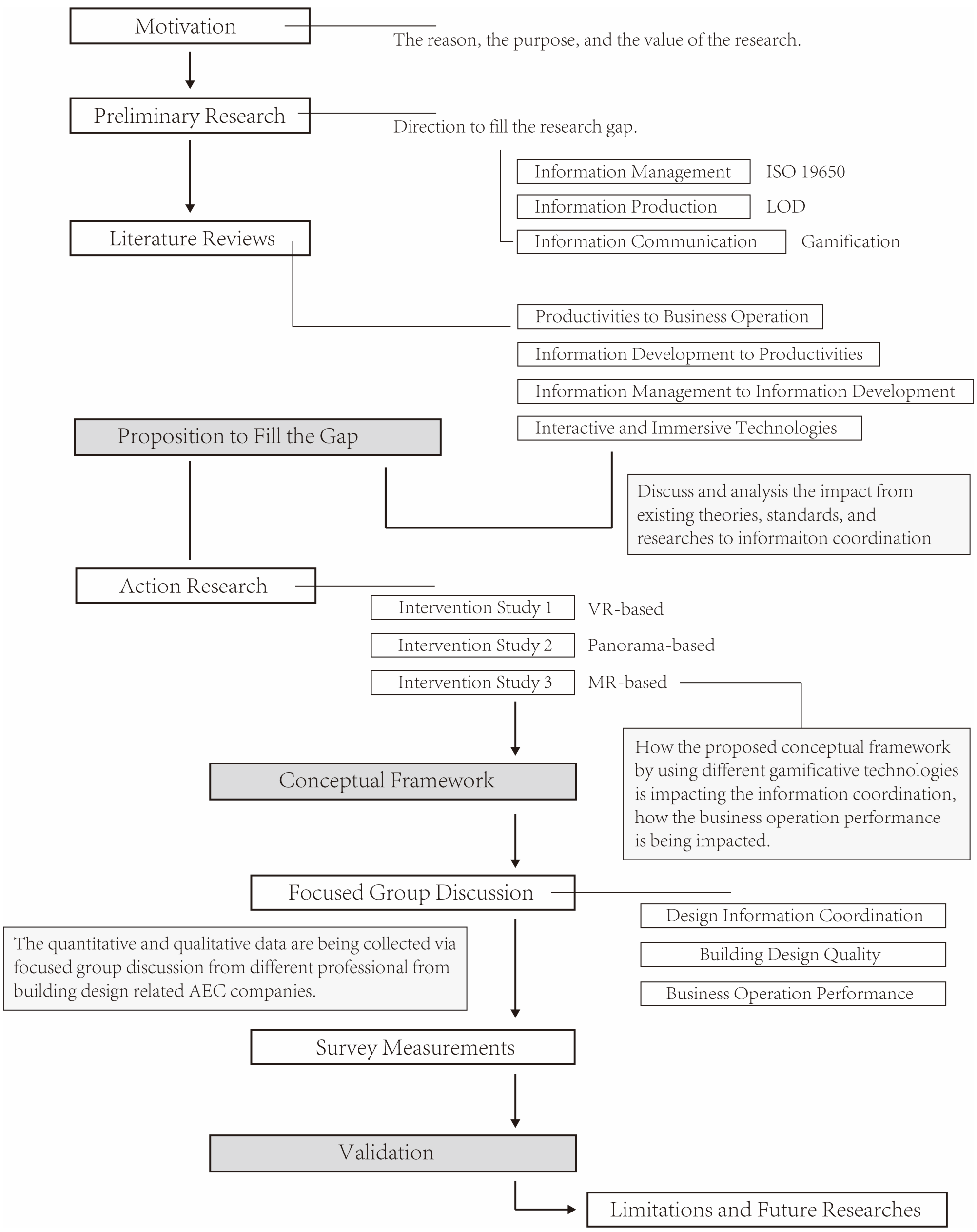


Figure 3.2 a: Research Design Progress

(Figure 3.2.a) shows the research process steps, and three stages of the conceptual framework proposed after each research process. The first stage framework is based on the findings of preliminarily research and literature review. The second stage framework is based on the evaluation of the intervention studies in action research, and the final stage comprises opinions from AEC professionals. Although the conceptual framework is evolved from multiple findings, there are still limitations for future research.

This research is divided into eleven stages, designed in a progressive way. The findings and the results from each stage will subsequently impact the next stage. Limitations will be identified from each stage to conduct further studies in the following stages. These stages are categorized into three parts: identify the issues, propose solutions, and validate.

The first stage is to discuss the motivation and research problems through the industrial background. The second stage is to identify what is the research question, which supplies the research aim and objectives. The first and second stages are written in Chapter 1. The third stage is to identify the first objective and to find relevant solutions through the literature review. The fourth stage is to discuss the advantages and propose a new solution. The third and fourth stages are written in Chapter 2. The fifth stage of the research is to design the research map, research methods, and research schedule. The sixth stage is to formulate data collection and analysis methods for each research objective; meanwhile, the research ethics will be considered and applied to obtain approval from UNNC's ethic office. The fifth and sixth stages are written in Chapter 3. The seventh stage is to design the experiments used in action research. The eighth stage is to analyse the data from action research. The seventh and eighth stages are written in Chapter 4. The nineth stage is to develop the conceptual framework based on the evaluation from the action research. The tenth stage is to finalize the conceptual framework. The seventh to tenth stages are written in Chapter 5. The eleventh stage comprises conclusions, limitations, and identification of future research, which is written in Chapter 6.

3.3 Research Philosophy

The research paradigm consists of research philosophy and research methods (Denscombe, 2008) following a commonly accepted framework for conducting research (Healy & Perry, 2000). According to common agreement in academia, the core aspect of the research philosophy is to investigate the nature of knowledge in a certain area. This research explores how building design can be improved, aimed at finding solutions for the issues in design management. The paradigm of this research is Interpretivism-Oriented, since there is more than one reality to improve design performance, and it mainly uses qualitative methods to make the interpretation. The philosophy of research is categorized into three parts: ontology to understand the nature of knowledge; epistemology to understand the approach to knowledge; and axiology to understand the value of knowledge (Blaikie & Priest, 2019).

The research ontologies are categorized into realism and anti-realism, according to common agreement in academia. Realism rigorously explores the objective facts in this universe, for example, the law of physics, which only come with one result. Anti-realism subjectively evaluates the feasibility of certain scenarios, for example, the aesthetic of an artwork, which can have multiple outcomes. Realism aims to understand unique facts about the world (Rosenkranz, 2013), while anti-realism aims to assess the suitability of the selected path (Dummett, n.d.). This research adopts anti-realism to find a suitable solution for increasing information coordination in building design.

Building design is the combination of natural science (engineering) and social science (humanity and art). However, in conceptual design and schematic design, more humanity and art are involved for consideration of spatial and aesthetic aspects. Therefore, this research is adopting the scheme of anti-realism to measure the feasibility of the proposition. Instead of scientific experiments such in physics and chemistry, this research mainly collects data from industry observation and discussion. The collected data focus on the personal reflection of the researcher and AEC professionals. Therefore, a relatively objective result can be generated to prove the suitability of the proposition.

Scientific research is based on fact, which is categorized as materialism. Inspired by Thomas Hobbes (1588-1679) and Francis Bacon (1561-1626), G.W.F. Hegel (1770-1831) made a significant contribution to dialectics for philosophical debate. This was followed by Ludwig Andreas Feuerbach (1804-1872), who proposed modern metaphysical materialism. Feuerbach's philosophy was inherited and developed by Karl Marx (1818-1883) and Friedrich Engels (1820-1895), and their famous statements of 1848. "The world is made up of matter" had significant impact on the philosophy of approaching reality in contemporary research. Also, "matter is in motion" and "exercise is regular" (Marx and Engels, 1848) explain the nature of the world and human consciousness, i.e., that human awareness is based on the facts of the world. Since building design is a complex process, and the process is a form of activity in the motion of various matter, human consciousness may vary for each scenario.

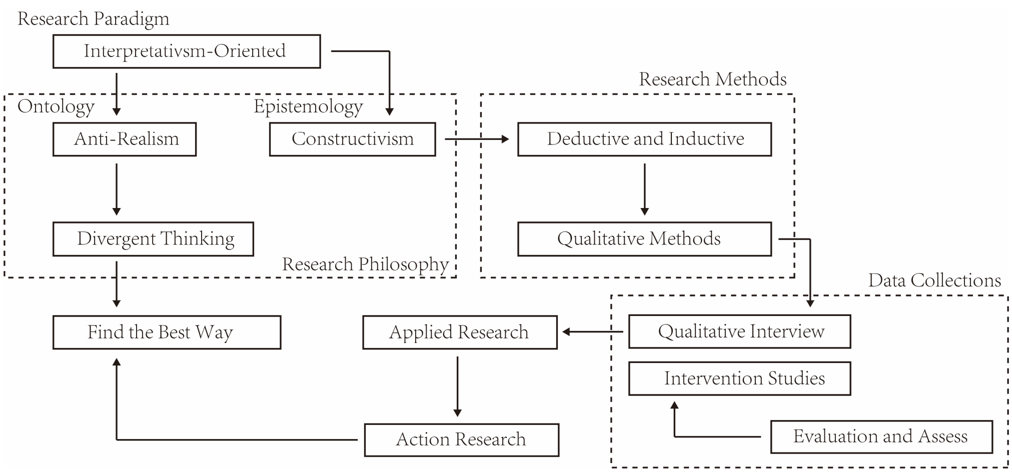


Figure 3.3 a: Research Philosophy

Thus, this research adopts the constructivist theory from interpretative-oriented paradigm to investigate those realities based on different situations (Figure 3.3.a). There is more than one reality, and this research will interpret one of the potential solutions to direct building design business operation. According to Marx (1844), subjective depends on objective; it can surpass objective but cannot be separated. Therefore, all scientific research must obey the law of nature. Marx and Engels (1848) stated that all facts in the universe are cognoscible, i.e., all objects are capable of being known, and that all scientific research must adopt Inductive and Deductive methods raised by Aristotle (384 BC- 382 BC) to explore the nature of knowledge. Marx's view of science (1877) inherited Aristotle’s philosophy, which highlights the importance of using precise evidence to investigate objects. Therefore, research must explore knowledge and solutions based on observed facts and must use those rigorous methods.

Karl Popper (1902-1994) highlighted the importance of interpretivism rather than positivism, arguing that experience-based interpretation carries greater weight in the process of inductive reasoning. One of his core values was that the development of science depends on interpretivism. Research is categorized as either fundamental or applied. Fundamental research investigates new knowledge while applied research addresses a particular problem (Bryman, 2012). This research is applied, as it intends to solve a specific issue in building design, i.e., how information can be efficiently coordinated for improving design quality. It also follows the action research method to find a direction for building design companies to improve the performance of their business operation, and uses qualitative methods, both inductive and deductive, to interpret the research question.

The syllogism proposed by Aristotle for deductive reasoning includes three parts: premise, middle statement, and conclusion. The premise is widely accepted theories, and the middle statement is observations from the research (Fredal, 2020). If the findings from research match with the premise, then the findings can be validated for drawing a conclusion. Through this research, the premise is that building design quality can be improved throughout an effective management process. The middle statement is that efficient information coordination can improve the design management process. Therefore, the conclusion is that efficient information coordination can impact the quality of building design. Hence, this research focuses on finding solutions to improve building design information coordination.

On this basis, this research adopts both the inductive and deductive approach (Figure 3.3.b) from the existing theories, specifications and standards to analyse the advantages and limitations. From the integration of those advantages, the research has made a proposition. The proposed proposition has been deducted for experiment through action research by using three intervention studies, and has further developed the conceptual framework through evaluation. The conceptual framework is further deducted for qualitative data collection through focus group discussion. Based on the collected qualitative data, the conceptual framework could be finalized.

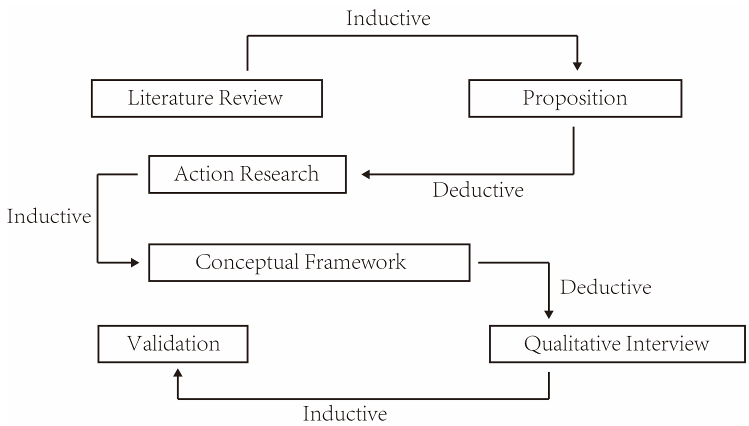


Figure 3.3 b: Research Approach

One of the most important differences between convergent thinking and divergent thinking is that the finding can only be correct or incorrect in convergent thinking while the finding can exist in multiple states in divergent thinking. There is no hard-line to define whether the finding is true in divergent thinking because the study is aiming to explore the best direction for solving the research question. Divergent thinking is widely used in open-ended questions for evaluating the best outcome and is very commonly applied in the research of creativities (Runco, 2011).

The paradigm of this research is interpretivism-oriented, aiming to find a new solution for increasing information coordination in building design management. The management itself consists of multiple solutions for solving a single problem; therefore, there are multiple possible directions in which the information coordination can be increased. The mode of thinking in this research needs to be divergent as multiple solutions and directions need to be investigated and evaluated. This research has broadly explored through literature, focusing on standards, methods, and procedures to find a feasible direction. The direction is further evaluated through action research, focus group discussion, and survey for conclusion.

The purpose of literature and systematic review in this research is to explore the possible solution to enhance the business operation performance of building design companies. Divergent thinking leads to a very broad review of existing literature. The scope of literature is not limited to design management but also focuses on numerous AEC technologies to seek the best possibilities. As a result, based on an extensive review of existing theories and practices, people, process, and technologies have been integrated for forming a proposition. This proposition is found to be the best direction which to increase information coordination in building design practice.

The action research in this study uses three intervention studies to investigate whether different interactive and immersive technologies can have the same impact in a gamificative environment. This is also a way of divergent thinking to evaluate the feasibilities of different technologies. Action research is a further investigation of the findings from the literature review. Based on the paradigm of interpretivism, the findings from the action research are neither true nor false. Divergent thinking helps this research to develop critical thinking regarding feasibility of a solution, and also helps evaluate if the direction is appropriate. The type of evidence used in divergent thinking is discussed in the next section.

The paradigm of this research is interpretivism-oriented and divergent thinking, which mainly uses qualitative methods to ascertain the most suitable direction, in terms of increasing information coordination in building design. Different types of evidence support research throughout the studies, categorized from qualitative to quantitative, with the qualitative evidence categorized into subjective and objective arguments. The objective evidence comprises opinions from different people while subjective evidence mainly consists of self-reflection. Some subjective evidence is also based on objective emotions, such as testimonials and appeals to authorities. Testimonial evidence relies strongly on people’s statements, which may or may not lead to an assertion (EskewLaw, 2015). Appeal to authorities is a way of seeking support from professionals, although limitations exist due to the scope of expertise (Nordquist, 2019).

Academia categorizes evidence from strong to weak, and different evidence can be utilized at different research stages. Strong evidence, also known as strong argument, is backed up by facts proven through precedent studies. A strong argument is sufficiently convincing to assert a conclusion for proposing a new solution toward a certain issue, since the evidence has been scientifically examined. Weak evidence, or weak argument, usually from personal experience, lacks sufficient investigation and requires further study; since the facts are not backed up by sufficient scientific research, it is not possible to make an assertion. Both types of evidence can contribute toward research findings, as weak evidence can provide a hint or at least a rough direction, while strong evidence can firmly support relevant feasibilities in proposing a hypothesis or proposition to fill a research gap.

3.4. Research Methodology

The research adopts Action Research to evaluate whether the proposed solution can improve the coordination of building design information. Action research is scientifically evaluated if the problems can be addressed by using certain methodological intervention (Corey, 1953). There are three main criteria of which to be aware during action research, which are, the target of action, the process of action, and the finding of action (Lewin, 1947). The target in this action research is to find whether an interactive and immersive environment in building design can improve information coordination. The process in this action research is to conduct studies by using three different interventions for making deductions. The finding in this action research is to judge whether different interventions are pointing toward the same results.

The process of the action research is mainly self-reflective, aiming to enhance the performance of a certain practice (Atweh et al., 1998). Several cycles are required in this research, and each cycle consists of planning, action, and evaluation (Lewin, 1948). The outcome of evaluation from each cycle will be further planned in the next cycle for action and evaluation. This repeat study can help to establish how to improve a certain scenario (Elliott,1991).

Action research uses three intervention studies, following the criteria of Robert Yin's (2014) 5th edition of case study research, using analytic generalization from the proposed framework to construct a logic that can be widely applied in other scenarios (Yin, 2014). Intervention studies use the same approaches as case study analysis because individual intervention is similar to an individual case. The criteria of multi-case analysis can be adopted in action research to analyse different interventions. Shapiro (1986) and Yin (2009) stated that a case study aims to explore and examine, to enhance the understanding of one or multiple aspects through real scenarios. The generalization from one case is considered as the "working hypothesis" identified by Lincoln and Guba (1985). Cronbach (1975) stated that the "working hypothesis" through generalization is widely accepted and Yin (2014) argued that it can lead to new experiments in other cases. From these perspectives, the research uses three intervention studies to objectively interpretate how the proposition can improve those factors in the building information coordination process.

This research adopts the method of action research, aiming to evaluate the feasibility of the gamificative environment in building projects. Technology used ranges from simple to advanced. A simple solution is first used in order to test if the direction is possible, with the second and third requiring significantly more effort to develop gamificative technologies. The evaluation assesses whether clients can understand what the design team has done, to see if decision-making is improved, and whether design team productivity is improved. The purpose of this action research is to test whether different gamificative technologies in different scenarios have the same impact on project understanding in team collaboration. Those technical implementations of the gamificative environment are designed and lead by the researcher of this thesis in team collaboration. The three intervention studies in action research use the following protocols:

- ✧ The chosen interventions are conducted through teamwork, since the conceptual framework is proposed for contributing to the theory of collaboration.
- ✧ The chosen interventions are of different types, since the conceptual framework is proposed for implementation in all building design scenarios.
- ✧ The chosen interventions adopt different technologies, because the conceptual framework is proposed for use of suitable immersive and interactive solutions in a gamificative environment.

For the action research, three interventions are selected for conducting multiple (embedded) analysis, which identifies factors from objectively structured observations and documentations that can be impacted by a preliminary proposed framework under three different gamificative technologies.

The three interventions chosen by this action study are a small residential house in Ningbo, a small office renovation in UNNC, and a staff restaurant in Ningbo airport. All the projects are in Ningbo since, according to Yicai.com (2019), Ningbo is becoming one of the New Tier-1 Cities in China, based on business activities, transportation convenience, population diversity, etc. The awareness of BIM adoption in Ningbo is apparent at policy level; in 2017, the Ningbo government issued the guideline for promoting BIM implementation. AEC industries in Ningbo are seeing swift growth, with similar progress in the AEC market in China in general (all regions follow the general requirements of the

National Standard). Therefore, this research chose a project in Ningbo as it is reasonably representative, without causing bias, and reliability is high because the process in Ningbo can be repeated in other Chinese cities.

For the prototype test of the gamificative environment, the three interventions chosen all have small volume; since it is not known whether the proposed solution will be successful, a large volume project would require too much resource input. The small project volume requires less resource inputs, risk is minimized from a cost perspective, so the experiment can be completed in a shorter time. Bias is not as issue; from modelling to coordination to visualization and interaction, the processes are the same whether small or large. Also, the intervention studies explore the relationship between factors in information coordination with the proposed framework in order to understand how these factors can be impacted, which are not affected by size. Therefore, reliability is high in this action research because the process can be repeated in each different scenario.

This research has used action research by identifying if the information coordination has improved through measurement from its development process and throughout the building design. The research firstly identified possible problems, then used the proposed solution to compare with traditional solutions to measure if those steps can be reduced and if the information can be enriched under three different gamificative technologies. The index of the research is to judge if the entire process is convenient, and the measurement of the convenience is determined from the procedures of data accessibility, visibility, and exchangeability. Moreover, the method of constructing accurate and sufficient data will also be considered as measurement. The three actions all use the same process to measure information coordination; hence the validity of this study is high because it has a clear research scope.

The action research uses different types of projects with three different gamificative technical approaches to test if the proposition can impact on information coordination in building design development. The Validity and Reliability of each scenario is carefully considered in this research; therefore, the collected data is suitably representative to support the analytic generalization. The data collection process in this action research is focused on:

- The process where the information models are built, integrated, and coordinated.
- The process where the data is visualized and presented.
- The process where the information container is established.
- The process where the data is created and exchanged.

Data is systematically collected from each case scenario in this action research through intervention studies in order to analyse and evaluate. The data is collected following a rigorous protocol, proposed from findings in the preliminary research and literature review. (Table 3.4.a) shows the protocols of data collection to identify the impact of LOD 350, ISO 19650 and Gamification on information coordination. Scopes of data collection are linked with each factor:

Table 3.4 a: Data Collection Protocol in Action Research

Predetermined Scopes	Factors	Solutions
Modelling, Integration, and Coordination	Data Accuracies Data Sufficiency	LOD 350
Visualization and Presentation	Data Visibility	Gamification
Management, Assessment, and Decision-making	Data Accessibility Data Exchangeability	ISO 19650

Three intervention studies use different gamificative technologies to evaluate if the proposition can impact information coordination in building design. The scope of data collection for each intervention follows Standards, Methods, and Procedures, and uses the same process to acquire the fully integrated and coordinated information models. Although the visualization and assessment of the project in each intervention is different, each is within the same scheme of People, Process, and Technologies. The collected data is then analysed for evaluation in a structured way.

Beyond data collected from the experiment itself, the research uses data from the communication process with project participants as supplementary support to the objectiveness of the action research. The communication is analysed in a structural way, and comprises understanding and satisfaction of the design and length of each communication. These factors can objectively reflect the performance of the design process from a third-person perspective. However, the third intervention is experimental based; therefore, there is little data from client communication during project development and hence, this is identified as a limitation. This will not affect the generalization since once the data reach saturation level, no additional data are required (Faulkner & Trotter, 2017).

Data collected from intervention studies in different stages are evaluated and analysed for induction. The data collected from this action research are mainly Information Model, Visualized Data, Information Container, and different Data Formats. The three intervention studies chosen by this research rigorously follow the protocol to structurally evaluate the effect of a gamificative environment on each factor, focusing on:

- Whether the accuracy and sufficiency of project data are increased.
- Whether the visualization of project data is improved.
- Whether the accessibility of project data is advanced.
- Whether the exchangeability of project data is enhanced.

The protocol used for evaluation in action research is focused on the features of LOD 350, ISO 19650 and Gamification to deduct whether the proposed gamificative environment impacts information coordination in building design development. During the experiment, the specific protocols are:

- ✧ Adopting the specification of LOD 350 in information modeling for spatial and functional coordination.
- ✧ Implementing the criteria of ISO 19650 in information management for design and modelling development.
- ✧ Utilizing interactive and immersive gamificative technologies in design visualization for presenting and decision-making.

Data collected during each stage of intervention study are inductively analysed based on evaluation outcomes. Through the evaluation, the research deduces the feasibility of whether a gamificative environment can be applied in building design for enhancing design companies' business operation performance. Impacts from one intervention are recorded for consideration in the next intervention. The findings are presented as a conceptual framework towards the end of the action research.

For the purposes of recording data, the research has designed a table (Table 3.4.b). This action research evaluates whether different gamificative technologies can have the same impact on each of the identified factors under the same scheme.

Table 3.4 b: Data Evaluation from Experiments

	Intervention 1 PC-based	Intervention 2 Panorama-based	Intervention 3 MR-based
Data Accuracy	LOD 350	LOD 350	LOD 350
Data Sufficiency	LOD 350	LOD 350	LOD 350
Data Visibility	Gamification	Gamification	Gamification
Data Accessibility	ISO 19650	ISO 19650	ISO 19650
Data Exchangeability	ISO 19650	ISO 19650	ISO 19650

(Table 3.4.b) shows the evaluation criteria for analysing the communication data with clients and project participants. The analysis of communication is mainly self-reflective, using key words to qualitatively identify the interrelation among different elements in building design. The key words focus on those related to design development in different stages regarding space and functions. A linked diagram is the output of analysis.

Table 3.4 c: Data Evaluation from Communication with Stakeholders

	PC-based	Panorama-based	MR-based
Understandings	If understand	If understand	N/A
Satisfaction	If happy	If happy	N/A
Length	If short	If short	N/A

The data from each intervention study are systematically recorded for evaluation. The findings will help to deduct whether the proposition can impact those factors in the coordination of building design information under different gamificative technologies with the adoption of LOD 350, ISO 19650, and Gamification. Further details are provided in Section 3.5.

3.5. Research Methods

The research is divided into three objectives, aiming at finding solutions to improve building design business operation performance. The first objective is to identify problems in current building design information coordination and management. Based on the findings of the first objective, the second objective is to explore how each potential solution can solve the problem and to investigate the features of each approach for integration. The third research objective is to validate how the proposed solution can effectively improve building design business operation.

According to the background study in the Chinese AEC market, with the understanding of problems and issues, the research needs to further identify the limitations in building design industries from the perspectives of experienced

AEC professionals. Hence, preliminary research via semi-structured interviews has been conducted to target the key aspects in design information coordination. From the findings of the preliminary research, a specific scope of limitation has been confirmed for seeking a new solution intervention.

To address those issues identified in the preliminarily research, the role of the literature review is to seek potential solutions. Through reviewing the literature, current standards, methods, and procedures (SMPs) for improving building design information coordination have been studied, and advantages and disadvantages of precedent solutions have been discussed for finding limitations and gaps. With comprehensive review of the literature, to fill the research gap, the outcome from precedent studies has been concluded, followed by a new proposed solution.

This research has identified three potential directions, which are: improving integration, interaction, and management during the information coordination process. However, it is not very clear what information needs to be integrated and how the information needs to be managed and interacted. Therefore, on the above basis, the field of information development, information management, and gamificative technologies has been researched. With the findings from in-depth reviews of ISO 19650, LOD 350 and Gamification, a preliminary conceptual framework has been proposed, for improving information coordination through a gamificative environment approach under the specification of LOD 350 and criteria of ISO 19650.

The research then uses action research to make further investigation through the experiments by using the induction approach. Based on the findings from the literature review and induction results from action research, this research has identified the role and relation between Gamification, ISO 19650, and LOD 350. Based on the findings from the action research, the research has further developed the conceptual framework, and discusses its impact on information coordination, building design quality and building design business operation through the collected qualitative and quantitative data from AEC professionals for finalizing the conceptual framework.

3.5.1 Objective 1

The first objective is to identify the issues and problems in building design companies. Therefore, semi-structured interviews are used during the preliminarily stage to confirm issues identified from the literature review by using primary qualitative data, and to investigate the required elements in the integration of building design. The interviews are conducted in building design and construction supervision companies to ask relevant questions of AEC professionals regarding their opinions on real project development. The purposes of the semi-structured interviews are:

- To investigate what problems exist in building design coordination between disciplines.
- To investigate what information needs to be developed in design production.
- To investigate what level of detail is required in design delivery documents.

The data is discussed in Chapter 1, Section 1.2.1 (**pp. 25-31**).

Research Sample

Interviewees were selected from three AEC disciplines related to the design process: architecture, structure, and construction supervision. Architecture and structure were chosen because they are the leading disciplines in design development; construction supervision was chosen because it is closely related to design delivery. The interview questions are different for each discipline, according to the different scopes of investigation. (Table 3.5.a) lists the purpose of each interview for the different design disciplines. The interview questions are attached at Appendix A.2.1.

Table 3.5 a: Design of the Semi-Structured Interview

Discipline	Purpose	Notes
Architecture Designers	To understand information design during building development.	Information Management
Structural Designers	To understand information coordination during design development.	Information Collaboration
Construction Supervisors	To understand issues in design delivery.	Information Detail

These three disciplines represent the information coordination process. Three samples were selected from each discipline, so the total number of interviewees was nine. This number of participants satisfies the qualitative requirement, according to Sandelowski (1995) and, according to the data collected from the semi-structured interviews, these answers give an in-depth insight into the issues concerning the building design development process. The representativeness of the samples is explained as followed:

- First, the samples are selected in Ningbo, which is a Chinese new Tier-One city, which not only has great economic prosperity but also has a large AEC market.
- Second, the samples are selected from a national certified Class-A design company and a construction supervision company. With a Class-A license in design and construction supervision, the company can undertake any size of civil project.
- Third, the samples are selected from qualified and experienced engineers who work in Class-A design and construction supervision companies.

For sample sufficiency in semi-structured interviews during preliminary research, Sandelowski (1995) argues that if the quality of sample has sufficient depth, innovation, and richness, there is no limitation to the sample restriction. In this part of the research, samples are from experienced AEC professionals from three major disciplines, and the interview questions cover most design aspects; therefore, the sample satisfies the requirement. Hence, with the above criteria, the chosen sample is representative of most of the Chinese building design market for targeting the issues and problems in building design development, and can be considered representative and sufficient.

Research Methods (Data Collection and Analysis)

The process of semi-structured interview for data collection is processed in a systematic way. Interviews for different design disciplines are conducted through the same process but with different interview questions. The following steps describe the process of primary qualitative data collection in preliminary research:

a. Design interview questions based on background study in the Chinese AEC market. (The interview questions are designed separately for different disciplines in building design and construction supervision to target issues from different perspectives.)
b. Permission sought from design and construction supervision companies regarding interviewing of employees.
c. Participants contacted and asked if willing to be involved in the research. Information Sheets and Ethical Approval Sheets sent to them for signature.
d. Participants contacted via WeChat and, due to the Covid-19 situation, sent aa questionnaire (i.e., they were not face-to-face interviews). Responses were received by the same means.
e. Data are translated to the English Language from the Chinese Language by the researcher. NVivo software was then used to analyse the collected qualitative data through clustering the coded elements.

The number of questions for each discipline is limited to eight to minimize disturbance to people's normal work. The data collection process strictly followed standards, methods, and procedures. All data are stored in a secure and confidential way for privacy purposes, and interviewees can choose to withdraw answers at any stage of this research.

In order to further explore the relationship between design management and spatial coordination, this research used NVivo software to conduct the qualitative analysis for investigating potential relations. The coding of nodes in NVivo selected the most frequent phrases in the answers, following terminologies from ISO 19650 relating to information management. Based on the findings from the semi-structured interviews, the research clarified how building design information needs to be developed.

The collected data from the semi-structured interviews coded in Nvivo followed the structure of identified aspects. According to background studies, two pairs are considered, which are: design and construction; information and management. The quality of design directly impacts construction, and information requires management. Management comprises coordination, cooperation, and communication; graphical information comprises shape, space, and size; design comprises components and disciplines. (Table 3.5.b) presents the node for coding in Nvivo:

Table 3.5 b: Coding Nodes in Nvivo (Semi-Structured Analysis 1)

Information	Shape Size Space
Management	Communication Coordination Cooperation
Design	Components Disciplines Precisions
Construction	N/A

The data analysis of semi-structured interviews aims to discover the interrelation between these factors by using clustering analysis in Nvivo. The clustering analysis finds similarities between different elements for investigating their relations. Each element is grouped based on the coded structure; the closer the groups, the more similar the element properties. Aside from identifying interrelation between information, management, design, and construction, the research also identifies the relation between each factor to evaluate how issues and problems can be solved in building design development.

Table 3.5 c: Coding Nodes in Nvivo (Semi-Structured Analysis 2)

Information Requirement	N/A
Information Production	Technologies Collaboration Coordination Management Communication Exchange (Information Transmission)
Information Delivery	N/A

Three stages of information development are identified by this research, which are: information requirement, information production, and information delivery. Information production requires technologies, collaboration, coordination, management, communication and data exchange (information transmission). This research aims to find how each factor in information production is interrelated with information requirement and information delivery. (Table 3.5.c) details the nodes for NVivo analysis for clustering results.

The two analyses of this semi-structured interview follow the same process for Nvivo coding, and the coding of each analysis uses individual documents. The coding processes in semi-structured interview using Nvivo are:

1. Carefully examine the collected data, separating sentence by sentence.
2. Evaluate to which nodes each sentence belongs.

3. Place the sentence into each node; one sentence can belong to multiple nodes.
4. Check if the coding is correct.
5. Analyse by using clustering function in NVivo.
6. Output the results by using different coefficiencies.

The results of the data clustering analysis from NVivo are presented as a tree diagram. Clustering results are grouping based on most similarities; therefore, if two elements have the closest positions in the clustering diagram, it is assumed they are related. Based on each level of relation between these facts, a map for investigating their impacts has been designed.

Limitation

The limitation of the semi-structured interviews is that the sample is from only two companies. Therefore, although data is representative in reflecting issues in building design, it cannot cover all aspects and concerns.

3.5.2. Objective 2

The second objective is to understand how LOD 350, ISO 19650, and Gamification can impact on building design information coordination. Therefore, the literature and systematic reviews aim to find potential solutions that can improve information coordination in building design development for enhancing the business operation of building design companies. The purpose of literature and systematic review in this research is to comprehensively explore those existing Standards, Methods, Procedures, and Technologies in AEC industries. In particular, the features of LOD 350, ISO 19650, and Gamificative Technologies are explored during the literature review.

With the findings from the literature review, action research is used to test the findings for evaluating the role of LOD 350, ISO 19650, and Gamification. This research follows the Action Research Paradigm Protocol (ARPP) to objectively evaluate the processes and outcomes of each intervention study. According to LeBlanc A. (n. d), ARPP requires the researcher to keep an open mind. The purpose of the action research is to discover:

- How can LOD 350 and ISO 19650 be integrated to impact the gamificative environment?
- How can the gamificative environment impact decision-making in building design?
- How can Chinese building design business operation be impacted by the gamification process?

The action research method is discussed in Chapter 3, Section 3.5.3 (**pp. 219-228**).

Systematic and Literature Review

Systematic review investigates whether an interactive and immersive visualized gamificative environment can improve information coordination in building design. With the findings from the systematic review, the research uses literature review to comprehensively explore how an interactive and immersive visualized gamificative environment can impact on building design information coordination to enhance business operation performance. The systematic review measures the feasibilities, while the literature review explicitly focuses on how the design team's productivity can be improved through adopting an interactive and immersive visualized gamificative environment (See Figure 3.5.a).

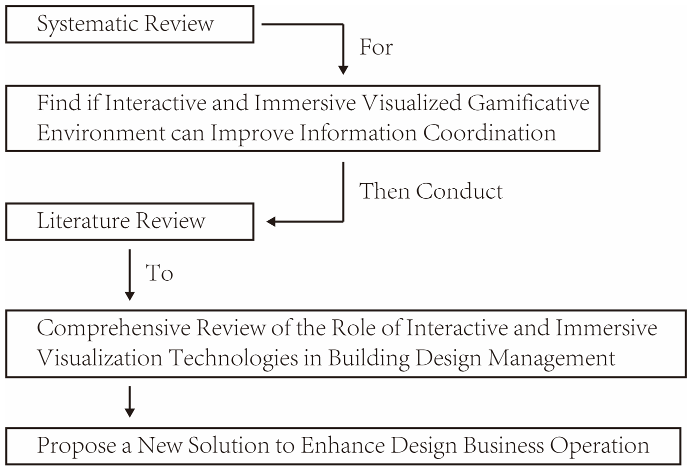


Figure 3.5 a: Interrelation Between Systematic and Literature Review

The search engines mainly used for searching the literature are NUsearch (Provided by University of Nottingham) and Google Scholar. Through the literature inclusion, the key words used by the researcher mainly focus on Business Operation, Building Information Modelling, Building Design Management, Lean Management, Interactive and Immersive Technologies, Gamification, and Collaborative Culture. The selected literature is managed by EndNote software for further classification and study. The literature is mainly from four databases: CNKI (China), ProQuest (US), Springer (Germany), and ScienceDirect (Netherlands).

The literature review explores issues in the current Chinese building design market in order to identify its current situation and find solutions, thus to find the gaps which can be addressed by this research. The review comprises five parts relating to building design related AEC fields:

- Precedent studies of information coordination in AEC industries, which focus on technologies, management, and standards.
- The impact of productivity on building design business operation.
- The impact of information development on productivity, focusing on the

building design process.

- The impact of information management on information development, focusing on ISO 19650 and LOD 350 in design production through BIM implementation.
- The utilization of interactive and immersive technologies to fill the gaps in precedent studies.

The literature review is based on the findings from research. Based on the findings, this research further explores the features of a gamificative environment in a comprehensive and detailed way to evaluate its feasibility to increase information coordination. According to the findings, a gamificative environment is likely to increase information coordination in building design for enhancing the business operation. The literature review explores which features and characteristics can impact building design information coordination and why.

The literature review first looks at business operation in building design companies to understand what factors determine its successfulness. Then the research examines building design management to understand the process of project development. Having understood building design business operation and building design management, the research further goes into information development, integration, and coordination to evaluate the impact of information management on business productivity, the impact of information development on information management, and the impact of interactive and immersive technologies on information development.

Information management explores how the criteria of ISO 19650 can contribute to building design management, while information development explores how the specifications of LOD 350 under BIM implementation can contribute to building design development. Through understanding information development and management, this research evaluates the importance of people, process, and technologies integrated with standards, methods, and procedures. The role of the gamificative environment is further discussed to argue its feasibilities to increase information coordination in building design.

The literature review comprehensively identifies the impacts of each factor in the gamificative environment on building design business operation. The literature is consistently reviewed in three parts: impact of productivity on business operation, impact of information development on productivity, and impact of information management on information development. With the identified impacts of LOD 350, ISO 19650, and gamificative technologies, this research evaluates the feasibility of using a gamificative environment to increase information coordination. Limitations identified from the systematic review are compared with findings from the literature review to discuss the advantages of the proposed position.

Protocol of Systematic Review

Findings from each part of the review are interrelated for analytic generalization, with each issue of the information coordination linked with potential solutions for proposing a holistic way to improve the building design collaboration process. Literature review provides a comprehensive understanding of current theories and practices, while systematic review is a specific investigation of particular solutions in building design information coordination (see Figure 3.5.b).

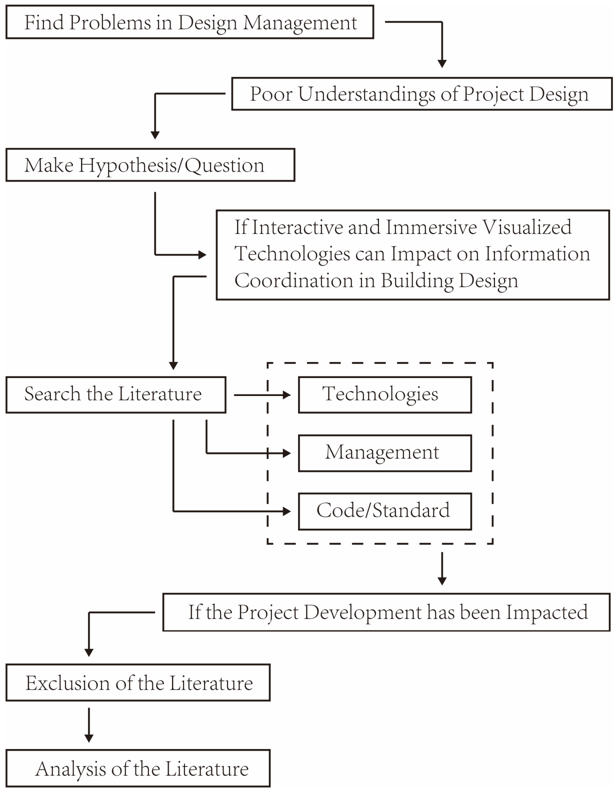


Figure 3.5 b: Protocol of Systematic Review

Therefore, the objective of systematic review is: to ascertain whether information coordination in building design can be improved through adopting an interactive and immersive visualized gamificative environment? To achieve the objective, this protocol consists of database selection, scopes and keywords, inclusion and exclusion of literature, and data analysis.

The systematic review identifies important aspects in the coordination of building design information. The review filters literature from more than 500 papers to select those relating to information coordination in AEC projects. The literature covers three categories, which are: design management, AEC technologies, and codes and specifications. The purposes of the systematic review are:

- To explore if information coordination can be impacted by interactive, immersive, and visualization technologies.

- To explore if information coordination can be impacted by collaboration, integration, and communication.
- To explore if information coordination can be impacted by procedure, methods, and management.

The protocol discusses the scope of literature, inclusion and exclusion method, and analysis process during the systematic review.

The systematic review is divided into three categories, which are, building design management, AEC technologies, and relevant building codes. The data analysis focuses on whether this literature has solved the issues of information coordination and, if so, how. Through this systematic analysis of the literature, the research has discovered features for further investigation.

Approximately 617 pieces of literature relating to AEC related studies have been selected from databases. These samples are from three main fields: building design regulations and code, state-of-the-art technologies in AEC industries, and building design business operation. The explanation of each area is listed in (Table 3.5.d):

Table 3.5 d: Areas of Precedent Studies

Fields/Areas	Details	Notes
Codes	Purpose of building design codes, interrelation with information coordination.	
Technologies	Role of AEC technologies in building design, interrelation with information coordination.	
Management	Relation between business operation and information coordination.	

Each of the areas has been subcategorised (see Table 3.5.e). Beyond exploring how design projects are managed, codes and technologies are also carefully studied. Building codes regulate what type of information is required for design aspects and BIM codes regulate how to properly develop the information model to correctly build the database for the design project. The purpose of exploring AEC technologies in building design is to investigate their role in project development and to confirm whether these technologies are used for increasing information coordination.

Table 3.5 e: Categories of Precedent Studies

Categories	Subcategories	Notes
AEC Codes	Building Codes	Requirements in Building Design
	BIM Codes	Regulations in BIM
AEC Technologies	VR/AR/MR	Various Technologies selected for exploration of how information coordination can be impacted.
	Gamification	
	Internet of Things	
	Sustainable	
AEC Management	Project Management	Management in AEC projects is similar, for a comprehensive exploration, literature from different projects has been selected.
	Design Management	
	Facility Management	
	Information Management	

The AEC code parts explore whether building codes and BIM specifications regulate areas relevant to information coordination. The part on AEC technology filters whether coordination of design information has been impacted by state-of-the-art technologies, and the AEC Management part selects literature that identifies potential solutions for solving the problems in information coordination. The software used to manage the literature is EndNote X9, due to its strong capability to hold and classify imported material. The classification in EndNote is based on the categories listed in the above table.

Inclusion and Exclusion of Literature

The databases used by this research to search the literature for systematic review are primarily based on *NUsearch* and *ScienceDirect*. The search methods use both title and keywords; the search is not limited to a publication year or region, and the search language is restricted to English and Chinese, since the research focuses on the Chinese AEC market. The types of literature are categorized into journals, books, and standards. Grey literature such as conference papers is also selected for covering state-of-the-art research. (Table 3.5.f) lists the source of the literature for conducting the systematic review.

Table 3.5 f: Inclusion of Literature

The filter/selection of literature is based on the following rules		
Databases	NUsearch,	Via University Networks
	ScienceDirect	Via University Networks
Reference Types	Journals	Database
	Conference papers	Database
	Books	Library/Online Library
	Standards	Library/Online Library
Publication Year	Not limited	
Publication Region	Not limited	
Publication Language	English and Chinese	
The results achieved by the references	Identified the issues in building design	
	Proposed solutions for building design	
	Improved the building design	

This section has discussed the methods of collecting literature for conducting the systematic review. Databases and data types have been selected which aim to cover the literature comprehensively. The research focuses on possible relations between building design information coordination and building design management to identify the role of information coordination. The next section will discuss the standard for filtering the literature, required to accurately target useful information from the large quantity of references.

Based on 617 pieces of searched papers, followed by rules of inclusion and exclusion, this research has carefully classified, selected, and narrowed down the literature. The selection of the literature follows the process shown in (Figure 3.5.c). The main requirement of the selection is to identify whether the literature discusses the coordination of design information. If the literature meets this requirement, the research then searches for impact on project design; once selected, the researcher explores which aspects the literature covers.

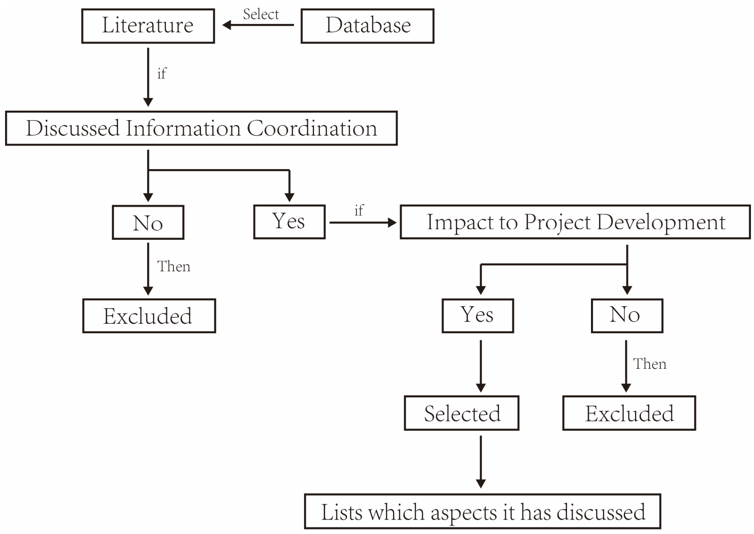


Figure 3.5 c: Inclusion and Exclusion of Literature

For the design theory itself, the date of the literature is not a major concern because architecture and building design is a discipline with a long history, and years of compiled studies and practices are all worthy of review. For the management and technologies parts, the focus is mainly on recent studies to ensure the procedures are state-of-the-art. The exclusion rule of the literature during the systematic review process is followed by:

- If the procedures used in the precedent study are not state-of-the-art.
- If the technologies used in the precedent study do not impact information coordination.
- If the area of the precedent study does not impact AEC sectors.

Literature Data Analysis

The objective of the systematic review is to investigate whether a gamificative environment integrated through LOD 350, ISO 19650, and Gamification can increase building design information coordination. As identified through preliminarily research, information coordination relies on design management;

and the research has identified three aspects in design management, which are, collaboration among different disciplines, integration of different information, and communication during different stages. This research proposes that these aspects can be impacted by interactive, immersive, and visualized technologies. The process of these impacts needs to follow relevant standards and codes, consisting of procedure, methods, and management.

The review of included literature is to discover whether the factors in design management, gamificative technologies, and building design codes are studied in precedent research, and whether these precedent studies confirm the impact of these factors for evaluating the feasibility of a gamificative environment in building design information coordination. The review is categorized in three parts, as follows: AEC technologies, design management theories, and AEC codes/standards.

Each literature category is reviewed differently. For AEC technology, the research looks at whether the study used interactive, immersive, or visualize technology; for design management, the research looks at whether the theory related to collaboration, integration, or communication; for standards and codes, the research looks at whether the code/standard regulates procedures, methods, or management. The finding results are ticked in each table for further evaluation and assessment. Where a link among these factors is established, their interrelations are evaluated to assess the feasibility of using a gamificative environment to increase information coordination in building design.

Based on the findings, this research assesses the limitations of precedent studies. Since building design is a complex process, a single theory, standard, or technology cannot satisfy its demands and, although the precedent studies have solved many problems in information coordination, they are not sufficiently comprehensive to support the whole process of building design; gaps and limitations still need to be addressed. Based on the findings from the systematic review, literature is further analysed in order to comprehensively investigate the impact of a gamificative environment on information coordination. The comprehensive literature review for enhancing building design business operation is covered in Chapter 2 (Section 2.2 to Section 2.4).

Limitation

Although the scope focuses on the AEC industry, many of these precedent studies are not specifically related to building design. Hence, it is not entirely certain that the solutions proposed by the precedent literature will increase information coordination in building design in particular.

3.5.3. Objective 3

The third objective is to discover whether and how a gamificative environment can enhance building design business operation. Based on the findings from the second objective, a further evaluation and validation was conducted, using action research to test whether different gamificative technologies within LOD 350 and ISO 19650 can have the same impact on design information coordination for establishing sufficient understanding.

The purposes of the action research are:

- To evaluate if different technical solutions can build and be implemented in building design development.
- To evaluate if different technical solutions can establish sufficient understanding for efficient decision-making in building design development.
- To evaluate if different technical solutions can be adopted in different use cases to achieve the same effects.

To address objective 3, the researcher uses **Three Intervention Studies** (in Chapter 4, Section 4.2), with each study followed by communication data between design team and stakeholders, in order to understand people's behaviour based on how different integrated environments impact on their decision. Thereafter, based on objectives 1 and 2 including the intervention studies, the researcher reshaped the conceptual framework (in Chapter 4, Section 4.6) and then validated through a **Focus Group Discussion** and **Survey** (Chapter 5, Section 5.2 to Section 5.3).

Intervention Study

The results of the intervention study show the feasibility of implementing an interactive and immersive visualized gamificative environment in a building design project. Experiments in three interventions were successful, i.e., they lead to improvement of end-user understanding of project design. The intervention study explores the impact of different gamificative technologies, and the results show that different interactive and immersive technologies have the same impact in improving project understanding for increasing project information coordination and enhancing design team productivity. Moreover, the results of the intervention study show that the implementation of a gamificative environment depends on people, process, and technology under effective standards, methods and procedures.

Intervention Study 1 - Collaborative Gamificative Environment

The first intervention study in action research adopts a PC-based gamificative environment for enabling comprehensive understanding of the project by clients. This project was conducted before the outbreak of Covid-19, when people were still working face-to-face (eg. meetings, project deliveries, etc.). The innovation of this project is that the researcher established a new visualized environment to present the project design and enable communication via Instant Message tools to avoid repeat modification caused by poor project understanding. The detailed data analysis is discussed in Chapter 4, Section 4.2.1 (**pp. 253-273**) of this thesis.

The learning outcome of this study is that the researcher understands the impact of LOD 350, ISO 19650, and Gamification on building design visualization. This study uses a simple interactive technology to test if gamificative technology can improve people's understanding. Through the established gamificative environment, clients can comprehensively explore the design by themselves, in an interactive way, to understand project design regarding spatial and functional coordination. The requests and decisions are made in an efficient way, which subsequently impacts design team productivity and enhances business operation performance.

Research Sample

The sample of this study is a small residential house since residential houses have all usage functions, from living to entertaining to dining. Also, a residential house includes most of the building elements, and the kitchen area of a residential house comprises multiple disciplines which will likely be chaotic in terms of spatial and functional coordination. Therefore, this type of project is sufficiently comprehensive to cover most aspects that a building designer needs to consider. Hence, the scenario is suitable for representing general building design.

Research Method (Data Collection and Analysis)

The experiment method was used by the researcher in this intervention. The purpose of the experiment was to test if the interactive and immersive technologies integrated with LOD 350 and ISO 19650 work in a gamificative environment and to evaluate if client project understandings was improved. Simple technology was adopted in this study as the researcher merely needed to test if the direction is feasible or not.

For collecting the data, the design team first designed the building based on the site condition and client requirements. The design was drafted in a format of 2D diagrams and 3D graphical models, then developed into a 3D information model (BIM) and data exported into FBX format and imported into a game engine. To enable clients to interactively review the project, the design team further developed project in a game engine, tested the interactive technology and exported into an executable file for end-users to operate. Communication between the design team and clients regarding decisions on whether to accept or reject is via the instant message tool (See Figure 3.5.d).

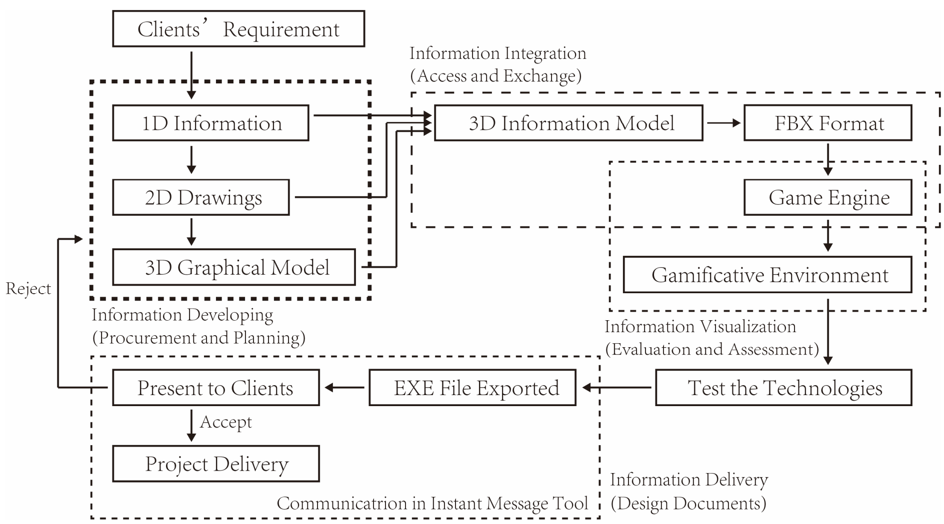


Figure 3.5 d: Research Process in Intervention 1

The data analysis to make the evaluation comprises four stages: information developing, information integration, information visualization, and information delivery. Evaluation of information development focuses on whether LOD 350 and ISO 19650 improve design quality (accuracies and sufficiency); evaluation of information integration focuses on whether design management (accessibility and exchangeability) is impacted; and evaluation of information visualization and information delivery focuses on whether client understanding of project design is improved and if decision-making efficiency is increased under the simple interactive and immersive visualized environment.

Research Limitation

The limitation of this study is that the sample is of only one type. Although the residential house is representative, it is not hundred precent sure whether the proposed solution works in other project types. Moreover, the researcher chose simple, interactive technology to establish the gamificative environment, which relies on the performance of a PC. Since a PC is not sufficiently portable, the data accessibility is affected, and hence a much lighter and more mobile solution is demanded.

Intervention Study 2 - Interactive Collaborative Environment

In consideration of the limitation of the first intervention, the second intervention chose a scenario of another project type, where much lighter and more portable interactive technology is adopted to fill the gap. In this intervention, the researcher used a web-based engine to establish an interactive and immersive environment for project visualization. Compare with the first intervention, the gamificative environment in the second intervention allows end-users to interact with the project via mobile devices. Since post-Covid-19, people are becoming accustomed to working remotely and are increasingly reliant on mobile technology for collaboration, and this intervention is highly suitable for reviewing the project design. The web-based interactive environment allows easier and faster data access, hence enabling faster decisions. The innovation of this project is that researcher has established a solution to enable different stakeholders to access project data remotely, increasing decision-making efficiencies. The detailed data analysis is discussed in Chapter 4, Section 4.2.2 (**pp. 273-293**) of this thesis.

The learning outcome from this study is that the researcher has identified the importance of data accessibility in project visualization. The cloud-based data container allows people to access the same information for making the evaluation. The interactive and immersive environment developed under LOD 350 and ISO 19650 allows end-users to acquire sufficient details to make decisions. The reason the researcher chose to follow this approach is to test the role of a cloud-based environment, since the information container requires an efficient Common Data Environment to support the project development. Moreover, beyond the findings from the first intervention, this intervention moved a gamificative environment to cloud to evaluate its feasibility and impacts. As a result, the productivity of the design team is increased, which subsequently enhances business operation performance.

Research Sample

The sample of this project is the interior design of a small office, chosen since it is designed for daily working purposes and consisting of many different users and stakeholders. The function needs to balance a variety of demands and hence, during the design period, several requirements need to be considered to satisfy different end-users. In office design, demands may range from types of furniture to type of material. The target of office interior design is different from residential houses, so this fills limitations gaps and the impact and the feasibility of a gamificative environment can be further evaluated.

Research Methods (Data Collection and Analysis)

The experiment method used by the researcher in this study tests whether a cloud-based gamificative environment works in project design. Through the experiment, the researcher evaluated whether a cloud-engine can improve data accessibility and impact project evaluation. Also, through the experiment, enhancement of project collaboration and communication is evaluated, and the impact on design team production capability is assessed.

For collecting the data, the design team first design the office via 2D drawings to allocate the furniture according to the functional requirements of from stakeholders. Once the 2D drawings are preliminarily accepted by clients, the design team further develops the 2D drawing to a 3D information model and exports the panorama images based on the information model. To make these panorama images interactable, the design team uploads them to a cloud-based engine, integrates the geospatial data, test the interactivity, and generates a QR code for sharing via the instant message tool. From here, the design team and clients communicate on design modifications (See Figure 3.5.e).

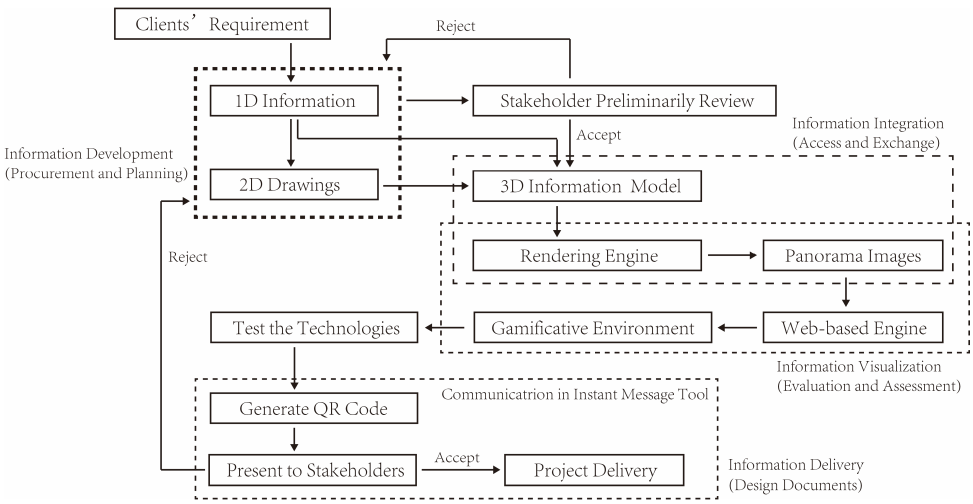


Figure 3.5 e: Research Process in Intervention 2

For data analysis, as in the first intervention, four stages are considered. Information development and information integration evaluate whether LOD 350 and ISO 19650 impact project detail construction, and research evaluates the impact of a cloud-based interactive environment on data accessibility regarding information visualization and information delivery. The researcher uses communication data between the design team and stakeholders to evaluate whether understanding of the project design is improved.

Research Limitation

The limitation of this study is that office interior design has limited spatial and functional coordination; hence the impact of a cloud-based gamificative environment is uncertain. Moreover, the interactive and immersive technologies adopted in this project have a limited view for design visualization. Therefore, a solution that can enable a comprehensive view and interaction via a cloud-based environment is demanded.

Intervention Study 3 - Integrated Collaborative Gamificative Environment

In additional to the findings from the first two interventions, and in order to fill the gaps in those limitations, the researcher adopts more interactive and immersive technologies to further test the impact of a gamificative environment on building projects. A different project type is chosen, while both cloud-based environment and wearable technologies are used. The wearable equipment allows end-users an immersive experience to visualize the project design, and cloud-based information containers allow different participants to access the same information for design review. The innovation of this project is that the researcher has established a new solution in terms of allowing end-users in a virtual environment to visualize via manipulation of holograms. The detailed data analysis is discussed in Chapter 4, Section 4.2.3 (**pp. 293-310**) of this thesis.

The learning outcome from this study is that the researcher has identified the impact of interactive and immersive technologies via a cloud-based environment on project understanding. ISO 19650 guides the project team on how to develop the project detail under the specification of LOD 350. The gamificative environment enables users to connect with project design to support decision-making, resulting in increased productivities of the project team. The researcher has adopted this approach to evaluate the feasibility of integrating people, process and technology in a single environment to enhance project performance.

Research Sample

The sample of this study is asset modelling of an airport staff restaurant. The restaurant project consists of multiple assets that need to be managed; therefore, accuracy and sufficiency of asset information is required to satisfy project demands. Beyond the geometrical accuracy, asset information also needs to be precise in terms of location and position. Hence, this type of project is representative to evaluate whether project understanding of asset information can be impacted by a gamificative environment.

Research Methods (Data Collection and Analysis)

The experiment method used in this research is to test the proposed technical solutions. The researcher tested whether the information detail developed by using LOD 350 and ISO 19650 can increase project understanding under a gamificative environment via a wearable headset, and whether a cloud-based interactive and immersive visualization environment can increase project teams' productivity.

To collect the data, the project team first modelled the asset information based on information provided by clients. In order to better visualize the asset data, the design team embedded the geospatial information into an asset information model and uploaded the model into a common data environment for converting into holograms. The hologram was projected via wearable headsets through the common data environment, to enable the end-users to touch and interact with asset information via integrated geospatial data (See Figure 3.5.f).

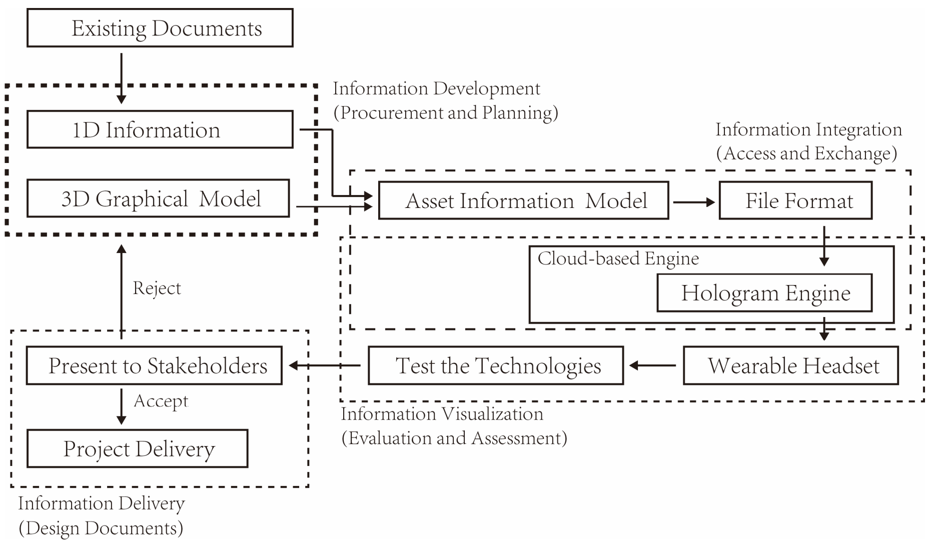


Figure 3.5 f: Research Process in Intervention 3

For data analysis in this intervention study, the researcher focused on four aspects. The focus of information development is how to accurately develop the existing information, and the focus of the information integration is how to efficiently present the developed information through the visualization process. This study analyses how LOD 350 and ISO 19650 contribute to asset information modelling, and how interactive and immersive technologies impact project understanding to increase project team productivity.

Research Limitation

The limitation of this project is that the project is small scale, and limited in asset information; hence, it is unsure whether the gamificative environment can impact larger asset information management to increase information coordination is. Moreover, this type of interactive and immersive technology is expensive to purchase (both hardware and software), and requires training to utilize the technology for interactive and immersive visualization.

Focus Group and Survey (Evaluation of the Proposed Conceptual Framework)

Form the evaluation results of action research, this research developed a conceptual framework to guide the building design business operation. To validate if the conceptual framework can work in Chinese building design companies, the research uses the opinions of AEC professionals from building design related industries to assess the feasibility of the impact of the conceptual framework. The validation comprises two stages: focus group to collect qualitative data on opinions regarding the impact of the conceptual framework on information coordination, building design quality, and business operation. Then the results from the focus group are used to design the survey to collect quantitative data for measuring the strength of each feature of the gamificative environment (Figure 3.5.g), the role of information management, and the capability of the building design business operation.

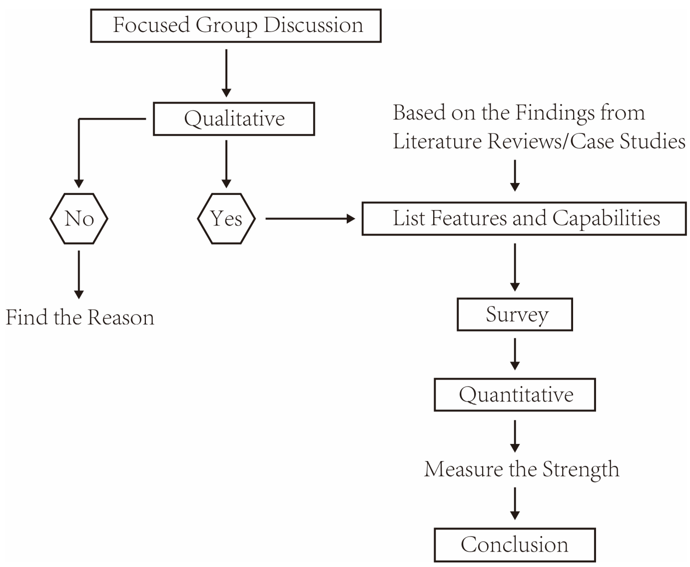


Figure 3.5 g: Link between Qualitative and Quantitative Data

Focus Group Discussion

The research uses a Focus Group Discussion (FGD) to collect the qualitative data for measuring the feasibility of the conceptual framework regarding its impact on building design information coordination, building design quality, and building design business operation. The data analysis is discussed in Chapter 5, Section 5.2 (**pp. 330-335**).


Photo 1

Photo 2

Photo 3

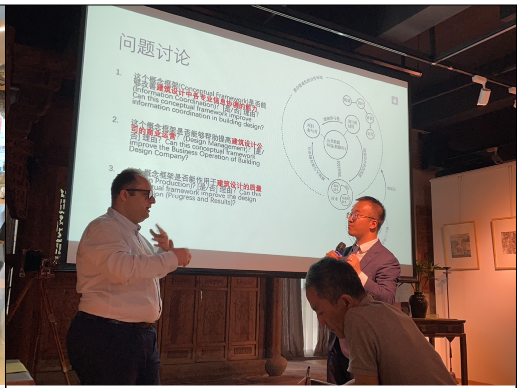


Photo 4

Figure 3.5 h: Scene Photos in Focus Group Data Collection

A Focus Group Discussion workshop was conducted in the reception area of a building design company on June 3rd, 2022 (See Figure 3.5.h). With the findings from the Focus Group Discussion, further quantitative data are collected via survey to measure the strength of each feature and its capability in the proposed conceptual framework. The focus group is a data collection method which collects a suitable amount of data for conducting the analysis. The purposes of the focus group are:

- To investigate if this conceptual framework can impact building information coordination.
- To investigate if this conceptual framework can impact building design qualities.
- To investigate if this conceptual framework can impact design business operation.

Research Sample

Focus group is a method of collecting qualitative data for identifying feasibilities regarding understanding certain problems, especially in social science (Tobias et al., 2018). The advantage of the focus group is that it can efficiently collect data in a simultaneous way for gathering opinions on a specific issue. Another advantage of focus group discussion is that the participants are usually from the same discipline with similar interests and concerns. The number of people involved in the discussion is neither small nor large (Andrew & Jonathan, 2006); therefore, this method can precisely target the problem through data collection.

The samples of the focus- group are selected from different types of AEC industry for ensuring data comprehensiveness. According to Chinese Building Regulations, a building project comprises four companies: Employer's Company, Design Company, Construction Company, and Construction Supervision Company. In a typical civil building project, these four companies are the representative bodies responsible from the outset for the delivery. Signatures and stamps are required from these companies from stage to stage during the project development. Notwithstanding that design companies have a full understanding of what they have done, the other three companies also need to establish a comprehensive understanding for ensuring the quality and schedule of project development.

- Employer's companies are in charge of the entire process and play the role of project coordinator, hence requiring sufficient understanding of the project design.
- Construction companies are responsible for project construction. They are required to clarify ambiguous points with the design company prior to construction.
- Construction supervision companies are responsible for ensuring that the construction meets with requirements. Therefore, they also need to understand spatial details of the project.

This research chooses also to invite a software development company because the findings from the action research show that the Gamificative Environment is highly dependent on technical support from IT mobilization. Samples from design and construction supervision companies cover those involved in preliminarily research to identify whether those issues in building design can be addressed by the proposed solution. Since the proposed solution aims at a collaborative perspective, in this way, the sample has sufficient variety for data discussion.

The purpose of this part of the research is to collect opinions from different AEC professionals regarding the proposed conceptual framework. These professionals need to have a particular background in AEC industries, ranging from management level to technician level. The samples need to be from leading positions in AEC-related industries to ensure reliability and validity. Since the research will also collect both quantitative and quantitative data, the sample size cannot be too small. The quantitative data is collected to support the qualitative data; therefore, the sample of quantitative data needs to be as same as the sample of qualitative data. Since there is no regulation regarding sample requirements in qualitative data collection, one of the commonly acknowledged methods to determine sample quantity is to judge if the selected samples are sufficiently representative for collecting high quality data.

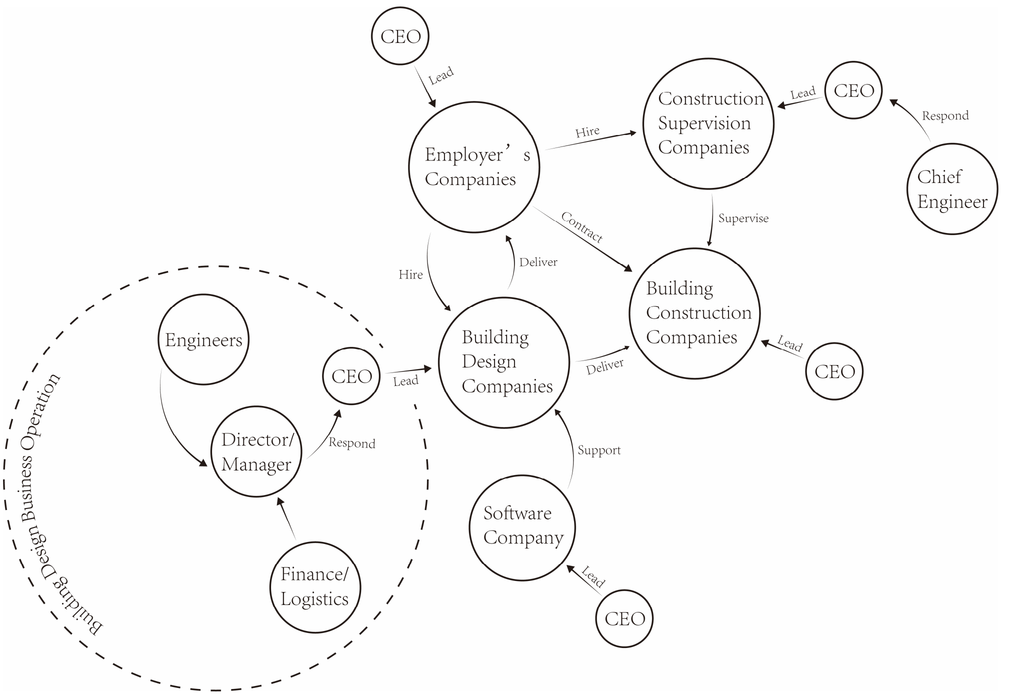


Figure 3.5 i: Data Sample Varieties

(Figure 3.5.i) shows the sample source of the data, which highlights that most samples are from building design companies because the conceptual framework is mainly being developed for enhancing the business operation of design companies. In design companies, comprehensive data is provided by different disciplines, such as engineers, logistics, and managers. In other companies' data collection focuses on CEO level because CEOs respond to the project development, along with the design company. The relationship between each company is highlighted, and the duty of each discipline is also illustrated.

Table 3.5 g: Research Sample

Company Type	Number	Position	Qualification	Sample
Employer Companies	3	President/CEO		3
Building Design Companies	2	VP/Chief Engineer		4
		Director/Manager		8
		Engineer	Qualified Engineer	6
Construction Supervision Companies	2	CEO/VP		4
		Chief Engineer		2
Construction Company	1	CEO/VP		2
Software Company	1	CEO		1
Total Sample	**9**			**30**

This research uses focus group as a data collection method, since focus group discussion can collect large amounts of data within a short time, from many people and at the same time. In total 30 people from nine different companies attended the Focus Group Discussion (Table 3.5.g). Twenty-eight answers were submitted, two of which could not be used due to the answers not meeting requirements. Therefore, the valid sample is 26 out of 30.

A focus group is used as a technique to efficiently collect data. The number of participants follows Sandelowski (1995) in that if the quality of sample meets with research requirements, then the sample does not have limitations. The most common sample size in focus group discussions is 3 to 21 participants, according to the findings of Nyumba et al. (2018). If the sample size is more then 12, the most appropriate method is to divide into different groups (Nyumba et al., 2018). Therefore, this focus group was divided, with around 10 people in each group. Thus, the data sample meets the requirements.

Research Methods (Data Collection and Analysis)

This research uses Focus Group Discussion (FGD) as a method of collecting data due to its efficiency. Although the Focus Group Discussion is a qualitative research method, quantitative data can also be collected as a supplement to the qualitative data. The reason for choosing this method is that it enables the most efficient data collection, as individual collection would consume a massive amount of time. Therefore, focus group discussion is the fastest way to simultaneously collect qualitative and quantitative data from a number of people. The samples are carefully selected for ensuring validity and reliability, based on people's professionality and expertise.

The focus group discussion consists of three stages:

- Stage 1: To estimate the focus group size, and to find a location for holding the events.
- Stage 2: To send invitations to participants, to confirm the event date, and to prepare facilities for events.
- Stage 3: To hold the event and to collect data.

At the time of the first there were no Covid-19 cases reported in Ningbo and the local government allowed face-to-face events, albeit with the size of event to be less than 50 people for safety purposes. The size of this focus group discussion was approximately 30 people, and hence the requirements of local pandemic prevention policy were satisfied. For professional aspects, the location of the event was in the reception area of a building design company, with permission to use the space obtained from the company's manager ahead of time.

The second stage is inviting participants. The researcher calls to ask if they are willing to participate in a discussion and, upon agreement, a formal invitation was sent with time and location. Facilities for presentation and data collection are prepared and tested beforehand for ensuring the quality of the event.

The third stage is holding the focus group discussion on the event day. When the participants arrive, they are required to sign three sheets: attendance sheet, research information sheet, and ethic approval declaration sheet. Once all participants are ready, the event can formally start.

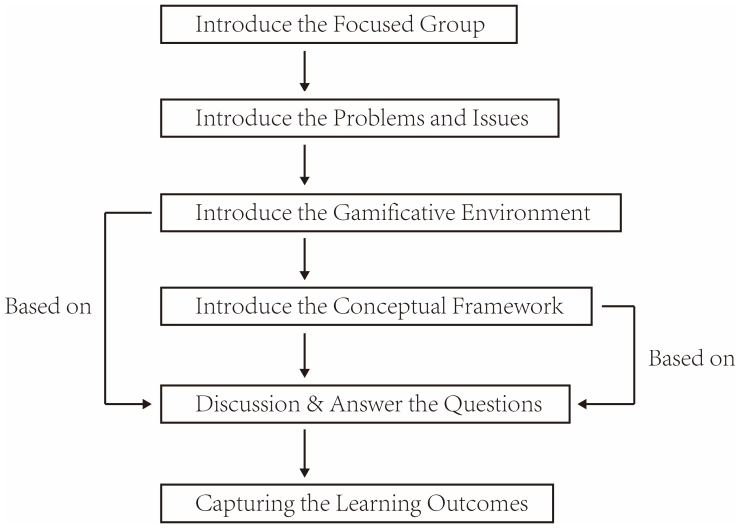


Figure 3.5 j: Focus Group Data Collection Process

(Figure 3.5.j) shows the process of data collection in a focus group discussion. The researcher is the facilitator, introducing the purpose of the group discussion, then highlighting the issues and problems in building design projects. The researcher firstly presents the adoption of a gamificative environment in building design, and then ask participants to give opinions. The seminar conducted mainly in the Chinese language. Prior to data collection, to ensure participants understand what the conceptual framework is about, the facilitator introduces three technical approaches of the gamificative environment, and discusses their impact on each factor of information coordination. Then the facilitator introduces the structure of the conceptual framework, and explains how the framework impacts building design information coordination, building design quality, and building design business operation.

The length of the focus group discussion is about 90 mins, including the introduction, presentation, discussion, and data collection. The collected data was stored according to relevant data-security regulations. No data was released beyond the research purposes. Any data for research publication is anonymous. Respondents could request to terminate the data collection process and withdraw the data before research publication.

In addition, the facilitator explains how the gamificative environment can solve current existing problems in the building design process from the findings in the research, to enable participants to have a holistic understanding of the proposed conceptual framework. After clearly introducing what the research has identified, the facilitator asks each participant to answer the following questions:

- Can this conceptual framework improve information coordination in building design?
- Can this conceptual framework improve business operation in a building design company?
- Can this conceptual framework improve building design production?

For each question, the answer is [Yes/No] plus the reason. From the Y/N part, the research collects quantitative data, and from the reason part, the research collects qualitative data. During the data collecting process, when answering questions, the facilitator allows people to give opinions in a free discussion. Once the data is collected, the facilitator requests that each participant gives an opinion on the learning outcome.

Two types of data were collected in the focus group discussion: quantitative and qualitative. Qualitative data were recorded in both audio and written format. The collected data were transferred manually from paper to electronic format. All the original copies were scanned to archive for future studies. Prior to the data analysis process, the following steps were carried out:

1. Transfer the data from audio format to written format.
2. Translate the data from Chinese to English.
3. Organize the data structurally.

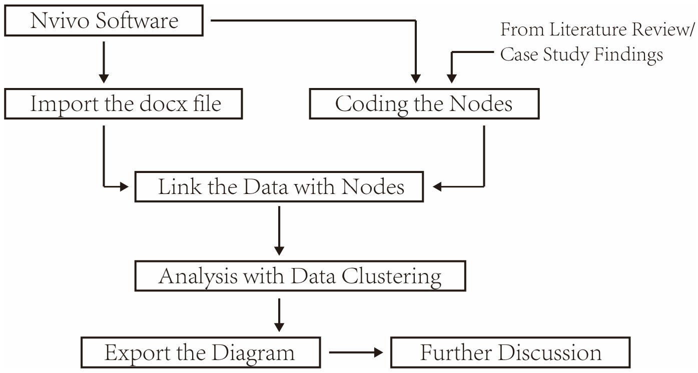


Figure 3.5 k: Qualitative Data Analysis of Focus Group Discussion

Once the data are transferred, translated, and organized, the researcher then counts the quantitative data, putting the qualitative data into coded nodes in professional software to identify the interrelation between different elements. The software used is NVivo because this is a very strong tool for analysing qualitative data (Figure 3.5.k). NVivo conveniently provides statistics for word frequencies and clustering analysis, as well as generating the graphics.

The research uses NVivo as a qualitative analysis tool to explore the relationships between the answers from the focus group. In NVivo, this research conducts the clustering analysis to compare the relations of items coded in the conceptual framework. The main nodes created in NVivo are Information Coordination, Business Operation, and Design Quality. The three nodes are the major categories identified by the research during the construction of the conceptual framework. Based on each node, the research further codes the sub-nodes; the structure of the coded nodes is shown in (Table 3.5.h).

Table 3.5 h: Data Coding in NVivo

Nodes	Sub-Nodes
Information Coordination	Common Data Environment Technologies Management Project Participants Communication

	Collaboration Detect Problems
Design Business Operation	Operation Cost Facilities and Resources Activities Decision Making
Building Design Quality	Immersive Environment Interactivities Visualization Optimization and Modification Design Process Modelling Process

In Nvivo, nodes for clustering analysis are coded based on the findings from literature review and action study. Two levels of nodes are coded. The first level consists of Information Coordination (for those relating to building information management), Design Business Operation (for those relating to business management) and Building Design Quality (for those relating to design development). The second level nodes are coded for detailed specifications. Those collected qualitative data are put into these nodes based on the content. Once all content is categorized into different nodes, the analysis button was clicked for computation. Coefficients of Jaccard's, Pearson, and Sorensen's are adopted to output the clustering analysis.

The purpose of using focus group discussion is to measure the feasibility of intervened solutions in building design development, and to objectively evaluate whether the gamificative environment can improve the information coordination for enhancing the business operation from the opinion of AEC professionals. With the findings, this research is further investigating the strength of those characteristics from the proposed conceptual framework via a quantitative survey.

Survey

The findings from the focus group discussion have been further validated from the quantitative-based survey by using the questionnaire to collect the primary data from AEC-related professionals. The purpose of the survey is to quantitatively measure the strength of characteristics from the proposed conceptual framework and to measure the strength of their impact on the business operation of building design companies through increased information coordination. The quantitative survey in this research is a further investigation of the findings from focus group discussion for validating the outcome. The data are collected by using a scale from 0 to 10 to measure the strength of the identified features in the conceptual framework. The purposes of the survey are:

- To measure the strength of each feature in the conceptual framework.
- To link the data strength with the findings in the literature review.
- To connect the feasibilities of the conceptual framework with future research.

The data analysis is discussed in Chapter 5, Section 5.3 (**pp. 335-380**).

Research Sample

The survey samples are selected from AEC-related companies. The survey was sent to most of the people who participated in the focus group discussion because they had already been introduced to the role and advantages of the gamificative environment. However, from a statistical perspective, since further samples are also required for the quantitative analysis, the survey was also sent to other AEC-related professionals, including building design disciplines, management positions in building design companies, technicians in construction supervision companies, academic staff in architecture schools, etc. According commonly agreed statistical studies, the formula used to calculate the sample number for research is:

$$n = \frac{z^2 \times \hat{\mathrm{p}}(1-\hat{\mathrm{p}})}{\varepsilon^2}$$

Where z is the score of the Confidential Level, ε is the margin of error, and p̂ is the population proportion. For the z-score, according to the z-score table, at a confidential level of 98%, the z-score equals 2.33. Due to the findings from the focus group data analysis, this expected margin of error is 15%, which is 0.15. The p̂ is normally set as 50%, which is 0.5 because the population proportion is uncertain. Therefore, the sample size is equal to:

$$n = \frac{2.33^2 \times 0.5(1-0.5)}{0.15^2} = 60.32$$

Therefore, the minimum sample size for the survey is 61. The total sample collected by this research is 67, where 20 samples are collected via paper copy and 47 samples in electrical format. The margin of error is re-calculated by using the following formula:

$$CI = \hat{p} \pm z \times \sqrt{\frac{p(1-p)}{n}}$$

Where p̂ is the population proportion, z is the score of the Confidential Level and n is the sample size. For the uncertain population proportion, p̂ is 50%, which is 0.500, while p is also counted as 0.500. For the Confidence Level, if the research adopts 95%, 90% and 85%, the z-score is 1.96, 1.645, and 1.44. Therefore, the Margin of Error of Confidential Level at 95% with a sample size of n=67 is:

$$CI = 0.5 \pm 1.96\sqrt{\frac{0.5(1-0.5)}{67}} = 50\% \pm 11.97\%$$

With the Confidential Level at 90% and sample size of n=67, the Margin of Error is calculated as:

$$CI = 0.5 \pm 1.645\sqrt{\frac{0.5(1-0.5)}{67}} = 50\% \pm 10.08\%$$

Also, with the Confidential Level at 90%, the Margin of Error with the sample size of n=67 is calculated as:

$$CI = 0.5 \pm 1.44\sqrt{\frac{0.5(1-0.5)}{67}} = 50\% \pm 8.80\%$$

Therefore, the Margin of Error is calculated as close to 10%, which shows that the Confidential Interval of the collected sample can reach 20% with normal distribution. The scale used for the survey is 0 to 10, which is 9.09% per each scale. Therefore, with 20% Confidential Interval, approximately two scale numbers can be ranged. With the defined value for the measurement of strength, this research defines that if the mean is above 6, then the impact is considered strong. Therefore, the collected data is analysed to see which interval of the measured scale is located.

Based on the findings from the literature review and evaluation from the action research, this research has proposed a conceptual framework for supporting building design companies in design activities and business operation. The identified features and capabilities are embedded into the conceptual framework regarding the contribution of the gamificative environment to building design management. The findings from the focus group further confirm the feasibility of the proposed conceptual framework. With the confirmed findings, this research will measure the strength of each feature of the gamificative environment in terms of impact on information coordination, and the strength of each capability generated by the framework in terms of business operation. Since the measurement cannot be simulated via computer software, but is achieved through measuring the opinions of AEC-professionals regarding each feature and capability.

Research Methods (Data Collection and Analysis)

The survey is designed to measure the strength of each capability; therefore, a measuring scale is used to collect the primary quantitative data. The scale ranges from 0 (not agree) to 10 (most agree) for each statement in the survey (The survey questions are attached at Appendix A.2.3). The chosen tool for the data collection is face-to-face data collection and an online questionnaire platform. Prior to data collection via the survey, the researcher introduced the gamificative environment to the participants by showing them the video of representative technologies. The research used paper copies and a cloud-based survey platform for distribution of the survey. For the paper copy, the researcher visited building design companies and construction supervision companies to introduce the concept of a gamificative environment face-to-face, and then request completion of the survey using the measuring scale. For the e-copy of the survey, the research used (www.wjx.cn) as an online platform to distribute the survey via WeChat (Figure 3.5.1). As an additional finding, it was discovered that people are happier to complete the survey in an on-line format. The video of the gamificative environment was sent to participants along with the survey to ensure understanding of a gamificative environment in building design.

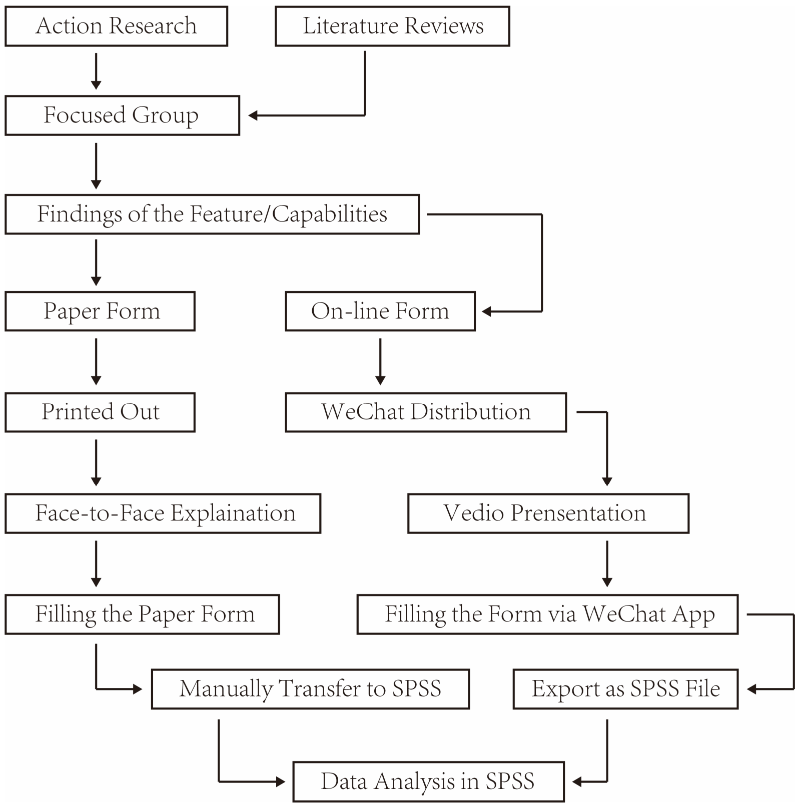


Figure 3.5 1: Survey Data Collection Process

The reason for the video being played to survey participants rather than inviting them to play via a VR or MR headset is that the equipment is currently not sufficiently sophisticated. As it stands, the VR environment is inconsistent in terms of what is seen and what is heard, commonly causing dizziness. Hence, VR and MR is not yet ready for mass distribution in building design development. However, there is excellent scope for future development in the gamificative environment.

Therefore, it was considered that people may have bias or misunderstanding of VR and MR, and of gamificative technology and environment. For this reason, rather than allowing people to experience these technologies, it was decided to explain to them through video how the gamificative environment impacts building project development. In this way, through the oral narrative of the researcher and through a projected video presentation, survey participants could understand the gamificative environment in a better way, thus leading to valid answers in the survey.

The tool used to analyse the data is SPSS, due to its professionality. After the data collection process, data from the paper copies of the survey were manually transferred to the SPSS software (Figure 3.5.m), and for the e-copy, the data was directly exported as an SPSS file. All the original copies were scanned to digital format for the archive, and all the original scripts were downloaded from the on-line platform for the archive. Archived data will be used for future studies and reference.

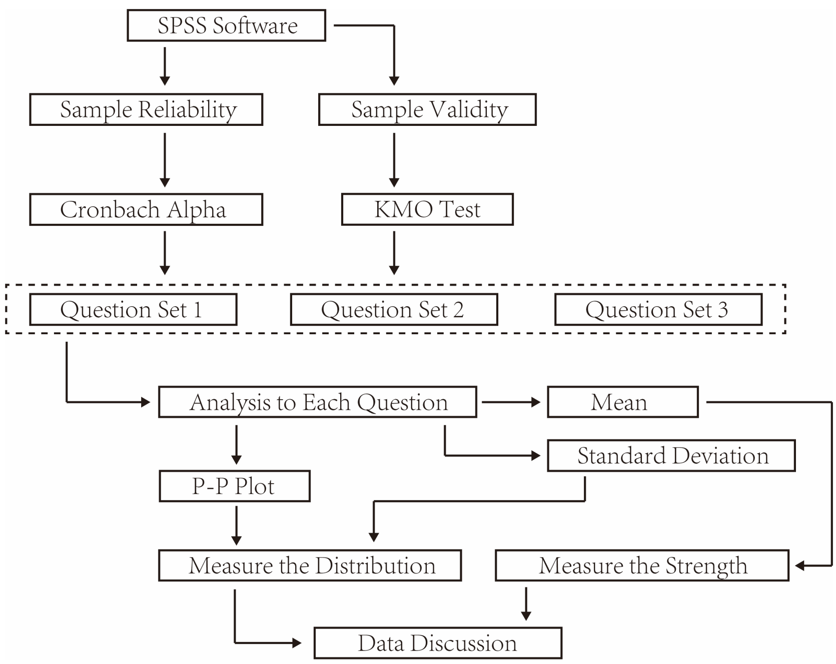


Figure 3.5 m: Data Analysis of the Survey Data

Once collected, the reliability and validity of the quantitative data were checked using Cronbach's Alpha. This validation is commonly used in statistics to measure whether the correlation between the collected samples has internal consistency. According to academia, if the value of Cronbach's Alpha is between 0 and 1, and closer to 1, then the reliability is high statistically speaking. If the value of Cronbach's Alpha is greater than 0.6, the reliability can be accepted, and if it is greater than 0.8, the reliability is considered strong. This research uses the Kaiser-Meyer-Olkin (KMO) test for measuring the validity of the collected data. The KMO test is also used in the measuring scale to compare the correlation between different variables. The value of KMO is also between 0 and 1, and based on the agreement of academia, the closer the KMO value is to 1, the stronger the validity. Commonly, if its value is above 0.8, the validity of the collected sample is very suitable for further analysis.

The survey is mainly categorized into three types of question, aiming to measure the strength of different features and capabilities in terms of impact on information coordination, design quality, and business operation. These three questions are designed in different orientations, hence, individual tests for reliability and validity are required. Once the collected data pass the Cronbach's Alpha test and KMO test, further analysis is processed to present the detailed data interrelations. This research used Mean and Standard Deviation (SD) for measuring the strength of each feature. The mean shows the average value of people's opinion. while SD measures the differences from the mean. The other two factors that this research measures are Skewness and the Kurtosis; Skewness is showing the extent to which data distribution differs from the median and Kurtosis shows the degree of data concentration.

The software being used for the statistics calculation is Statistical Package for the Social Sciences (SPSS), a comprehensive tool to conduct quantitative data analysis. It does not require manual programming of the functions, and all calculations are integrated for automatic generation. Therefore, a lot of time and effort is saved in data analysis. Also, all the diagrams of the data presentation are generated by SPSS.

Three aspects are measured in terms of the impact of the gamificative environment to increase information coordination, the increased information coordination within the gamificative environment to improve building design quality, and the improved building design quality to enhance design companies' business operation. Features of the gamificative environment, roles of information coordination within the gamificative environment, and capabilities of building design business operation within the gamificative environment are evaluated in this data analysis process. With the findings from the quantitative survey, this research validates the impact of the proposed conceptual framework.

3.6 Research Limitations

The limitations of the research are that the samples used in this research are all within Zhejiang Province. Although Zhejiang Province is one of the most developed regions in China and the architecture design business operation is similar in domestic cities, there may be some differences in many other regions. Another limitation is that, although different project types are used, the scenarios used in action research are all on a relatively small scale. Although small scale projects are similar to large projects from the perspective of information coordination, the gamificative environment has not been tested in large scale projects.

These limitations cannot be overcome in this research due to limited resources and time since, to cover the samples from every region in China would require a great deal of time in data collection and analysis. Also, to test the gamificative environment in a large-scale project requires long-term technical development. However, this research focuses on the Zhejiang Province and small-scale projects, with the assumption that the results are applicable to every domestic region and scale of building projects.

3.7 Research Ethics

This research has followed the university's research ethics application process to submit the related documents and forms for approval. Since the primary data source is interviews and focus group discussions from AEC industries, the research involves data collection from people. Hence, potential ethics issues have been considered. Participant Information Sheets were distributed, and Participant Consent Forms signed by interviewees and focus group discussion participants prior to data collection. The scope of questions asked and discussed is limited to AEC disciplines; no sensitive questions were asked. Therefore, the sensitivity of the research has been assessed as low risk.

3.8 Chapter Summary

This chapter has discussed the research design of the PhD study, which consists of research design, research methods, and research samples. The research is designed to validate whether the gamificative environment under LOD 350 and ISO 19650 can enhance the quality of building design information coordination. The methodology adopted by this research is mixed-method, which includes both qualitative and quantitative data. The research aims to enhance the building design business operation, and a conceptual framework has been proposed to address the problems in building design information coordination. For the investigation and validation process during this research, research samples were carefully selected, and relevant ethics issues carefully considered.

The research method used in this research is mainly action research to observe and to evaluate whether and how the gamificative environment can increase the information coordination in building design development for improving understanding. The plan of the action research is based on the findings from semi-structured interviews (for confirming the issues in building design development) and from literature review (for confirming the proposition to fill the gap). Three interventions are taken and evaluated during the action research for establishing self-reflection. The outcome of the action research is validated through focus group discussion and quantitative survey.

Chapter 4: Gamificative Environment Impact on Information Coordination

4.1 Introduction

4.1.1 General Principles

The findings from the literature review have identified four factors that will impact information coordination: Data Accuracy, Data Visibility, Data Accessibility, Data Sufficiency, and Data Exchangeability. The findings also identified the features of LOD 350, ISO 19650, and a Gamificative Environment, and their information coordination have been established. The findings from the literature review state that increased interaction between people and data will increase the coordination of information, and this research has identified three ways to interact with data: to produce the data, to access the data, and to exchange the data. Three major technologies from AEC industries have been included in information coordination, which are: Interaction Technologies, Modelling Technologies, and Collaboration Technologies (Figure 4.1.a). The proposed framework provides a way to increase performance to interact with information during the building design development, and this chapter tests the proposed solution through action research.

The action research is to explore whether the gamificative environment can enhance the information coordination in the building design development process by using three actions. Three intervention studies are being conducted through three case scenarios, which aim to make structured observations in order to ascertain whether different gamificative technologies can have the same impacts. Moreover, through the experiments in three actions, the impacts from different gamificative technologies on each factor of information coordination will be evaluated. Assessment and evaluation are being conducted after each action for making amendments in the next action. After three actions, a final outcome regarding the induction is concluded for summarizing the findings.

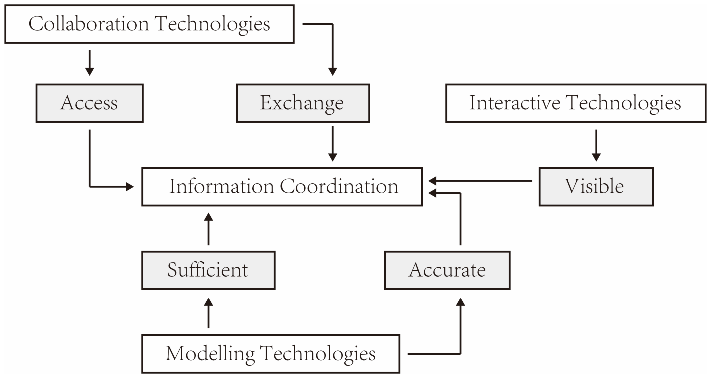


Figure 4.1 a: Impact of Major Technologies

Each intervention study is a scenario used by this research to implement different gamificative technologies. Starting from adopting the simplest gamificative technologies, further advanced gamificative technologies are being added in the next intervention based on the findings from previous evaluation. Induction in each use case is focusing on whether these technologies can enable sufficient interaction between participants and building design, and whether the understandings toward project design are improved.

4.2 Intervention Studies

The three interventions adopt the proposition during project development, which has achieved the expected results. From Section 4.2.1 to Section 4.2.3, this research interprets why these cases are successful through objective analysis of how the proposed solution those factors of information coordination in these intervention studies. The research methods of sample selection, data collection, and data analysis in this action research regarding to three intervention studies are discussed in Chapter 3, Section 3.5.3 (**pp. 219-228**). For the construct validity, the evidence is from the evaluation of collected data to judge if the problems are solved by using the SMPs of the framework.

According to findings from the literature review, there are three main types of problem affecting information coordination in building design development: communication, collaboration, and detail development. Each limitation of the traditional solution suggests a need, and based on findings from this chapter, a potential solution is proposed for each need. After careful investigation of each solution, this research makes a statement from the deductive analysis, which is to improve building design information coordination through an immersive and interactive approach by integration of core aspects in ISO 19650, LOD 350, and Gamification. (Table 4.2.a) is a summary of the literature review findings.

Table 4.2 a: Proposed Solution to Fill the Research Gap

	Issue 1	Issue 2	Issue 3
	Communication	Collaboration	Development Details
Limitations of traditional solutions	Communication is not efficient among different disciplines.	De-centralized information is not well organized.	Lack of depth in graphical information.
The Need	Improve visualization and interactivities.	Improve motivation and engagement	Improve management and specifications
Potential solutions	Gamification ISO 350	ISO 19650 Gamification	LOD 350 ISO 19650
Discussion	The features of ISO 19650, LOD 350 and Gamification can potentially address each issue in design information coordination. This research found through appropriate adoption of these features, that the performance of building design business operation can be enhanced.		
Statement	A Gamificative Environment built through specification of LOD 350 under criteria of ISO 19650 can potentially provide an immersive environment for visualization of building design data, which allows improved interaction between people and virtual environment for conducting decision making, thus leading to improved information coordination.		
Experiments	To test the statement made by deductive analysis, this research has designed three experiments in action research to conduct observations and collect data for inductive analysis		

The action research is exploring the feasibility of the gamificative environment in three scenarios, and each scenario is an intervention to explore if the gamificative environment can improve the information coordination in building design development. The action study is begun with the simple gamificative technologies, analysis of the pros and cons, and then adoption of further gamificative technologies in second and third interventions for concluding the findings. From the first intervention to the third intervention, the advantage of gamificative technologies is increased. When the findings from the first intervention study indicate the feasibility of the proposed solution, then more advanced technologies are applied in the next intervention for discussion as to whether different technologies can lead to similar impacts.

4.2.1 Intervention 1: Small Residential House

The most difficult part in this type of project is how to efficiently solve integration between different building elements to satisfy demand for spatial and functional purposes. The most common issues arising from these projects are spatial clashes and insufficient spatial clearance, which are caused by poor information coordination from 2D symbol-based inaccurate and insufficient design documents, low level visualization, poor accessibility of data, and inconvenient data exchange. As the complicated functional and spatial information needs to be coordinated with non-professional participants, the ability of the gamificative environment to improve understanding of the design project will be assessed in this action study.

Moreover, residential house design is the most common project in building design companies; therefore, this intervention is aiming to test and to observe whether the proposed solution can improve the coordination and collaboration during the design development, then to evaluate the potential business performance that can be enhanced.

The first intervention uses the simplest gamificative technologies to test if the interactive and immersive environment can improve understanding to increase the coordination of project information. As the study is mainly for testing the role of a gamificative environment, the selected scenario is a small but representative one. As a kitchen area comprises most building elements, ranging from architectural and structural components to MEP components, it is ideal for testing the coordination of spatial and functional information. Hence, the first intervention uses the kitchen as a scenario of why poor information coordination factors cause issues, and how the conceptual framework impacts these factors to enhance people's understanding. If the results from this intervention study indicate the role of a gamificative environment, more advanced technologies will be applied in the next intervention to examine whether different technologies have the same impact.

This project team consists of two academic staff (Dr. Georgios Kapogiannis, Dr. Craig Hancock), one PhD student (Tianlun Yang), and one MSc student (Ryan Jonathan). The role of the researcher of this thesis is the design of the entire building, proposal of the technical solution for a gamificative environment, and cooperation with the MSc student (Ryan Jonathan) to implement the gamification technologies into the building visualization. This project won first prize in the University Group in the China National-level Competition of Smart Construction, and the project findings were published at the FIG conference.

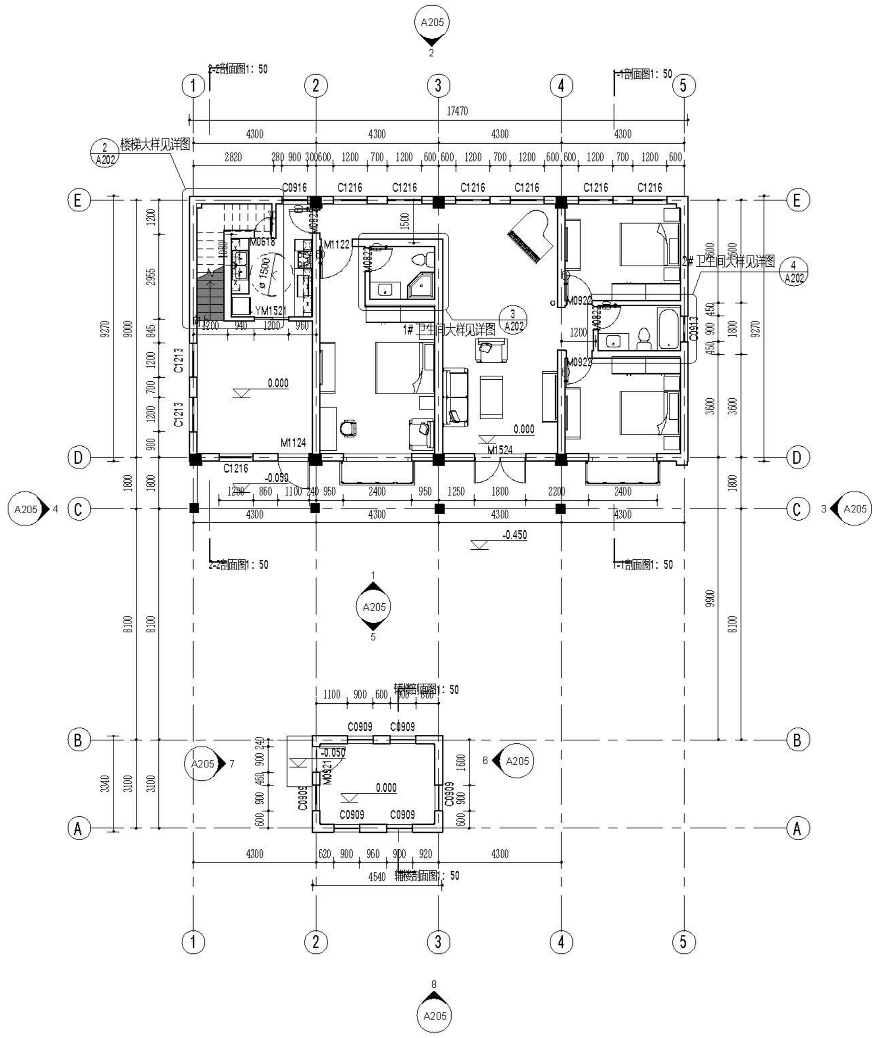


Figure 4.2 a: Intervention 1, the Villa House Planning

Results from the Experiments

Impact 1: Sufficiency and Accuracy of Data

The kitchen of a residential house includes many different elements; it comprises architectural components, structural components, utilities, and furniture. Although the 2D symbol can effectively represent their relation with planning, it is not efficiently presented from the 3D perspective. From AIA LOD specifications, the 2D-based symbol is only LOD 100 level, which contains no 3D information from a graphical perspective. In (Figure 4.2.a), the kitchen area is in the left above corner, adjacent to the stairs. The information is quite complicated in this area because it needs to satisfy both spatial and functional aspects to ensure the door will not clash with the stairs, and the space under the stairs can be used for other functional purposes. Since the 2D-based design document cannot reflect the 3D relation of different elements, all the coordination relies on the spatial imagination of the designers, which is likely to be jeopardized by human error. As a result, information in 2D representation is not sufficient or accurate enough, which will cause problems during construction and in post occupancy usage.

This research addresses these problems through modelling the 3D information under the scheme of the proposed conceptual framework, since an accurate model is the foundation for visualization and interaction. The project uses Autodesk Revit to enhance the detail of the 3D information model at LOD 350 level according to AIA LOD specifications, according to the requirements of each discipline. Models from each discipline are integrated and coordinated to detect clashes.

Figure 4.2.b.1	Figure 4.2.b.2	Figure 4.2.b.3

Figure 4.2 b: 3D Information Model of Kitchen Area

The above diagrams are screenshots of Revit models, showing integration of architecture, structure, and MEP. With the detail level in LOD 350, the coordination of geometric components could potentially identify insufficiencies. The actual graphical information of building components from different disciplines optimizes spatial aspects such as net clearance. The fragment model in (Figure 4.2.b.2) shows that the actual location and position of building components can be confirmed for spatial coordination. Modification and optimization have been made according to the detected clashes.

Inaccurate and insufficient data is caused by the limitations of the 2D symbol-based diagram. LOD 100 level is neither sufficient nor accurate enough to support coordination in clash detection and spatial clearance. One key element of the proposed conceptual framework is graphical development of the gamificative environment. Implementation of the LOD 350 specification, which requires that model components have actual geometric shape, with the assistance of the accurate 3D information model, enables the design team to ensure correct spatial integration and coordination.

Impact 2: Comprehensive and Sufficient Visualization

The information coordination needs to fully consider stakeholder requirements, since they are the post occupancy users, and the design team needs to have a regular meeting with stakeholders to report the progress of the design development. However, due to the limitations in traditional visualization techniques, the design cannot be sufficiently visualized to comprehensively show the design content, which will cause the confusion in understanding the project design. If the client cannot fully understand the project, they are most likely not well placed to make decisions, which will likely lead to dissatisfaction once the project is completed, in terms of not meeting expectations.

Although the coordination in 3D information models provides a clear spatial reference between each building component for design team assessment, it is too technical for stakeholders to understand. Hence, a much more straightforward method of reviewing design content is required. Traditionally, the development of 3D graphics is separate from 2D diagrams, since 3D graphics are only designed for generating rendering. Therefore, the graphics are not sufficiently accurate. Another issue is that images are output in a static way; this does not provide an immersive environment and holistic view for design teams and stakeholders. The limitation of traditional technology is that it needs multiple images viewed from a single point, and is not sufficiently interactive to support efficient decision making.

The experiment uses the intervention of the conceptual framework in the core aspect of the engagement through immersive and interactive visualization. The intervention adopts Unity3D as a visualization engine to create an interactive environment for visualization; (Figure 4.2.c) shows the outcome. Unlike static rendering output or the Revit UI view, the output from Unity3D enables users to explore every corner of the project design to evaluate spatial and functional coordination.

For the development of the gamificative environment, this experiment involved a series of steps. The 3D model from Revit cannot be directly imported to Unity3D, hence files from Revit were first converted to 3D Studio Max. Then, through the file exported from 3D Studio Max, the model was successfully deployed in Unity3D. Compared with the Revit information model, the Unity3D model is merely graphical, with rendered video and images that can be exported from Unity3D and enabling dynamic visualized interaction.

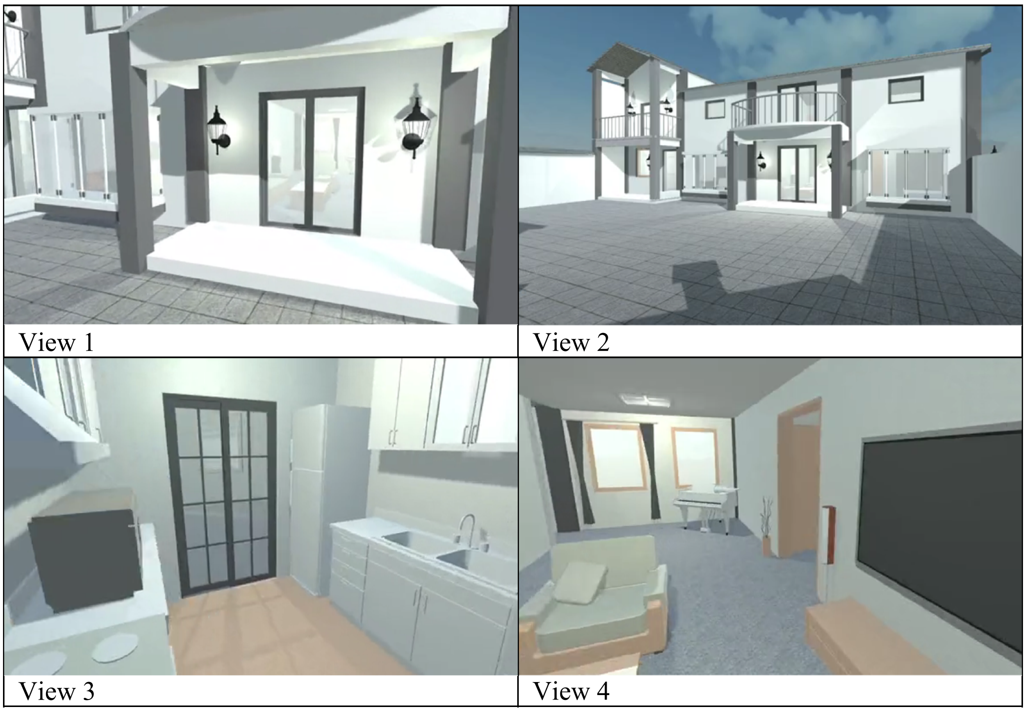


Figure 4.2 c: Scenes from Unity3D Engine

The gamificative environment was established for visualization in this experiment through the adoption of the Unity3D development platform. The PC-based game exported from Unity3D can be directly executed through Windows OS, enabling a comprehensive review for both the design team and stakeholders. Interaction between people and virtual environment allows navigation to the points needing to be viewed.

The proposed framework creates an interactive and immersive visualization environment for improving decision making in building design. Although the project design output from Unity3D in game form can increase interactivity between people and the virtual environment, it is still not sufficiently immersive to increase engagement.

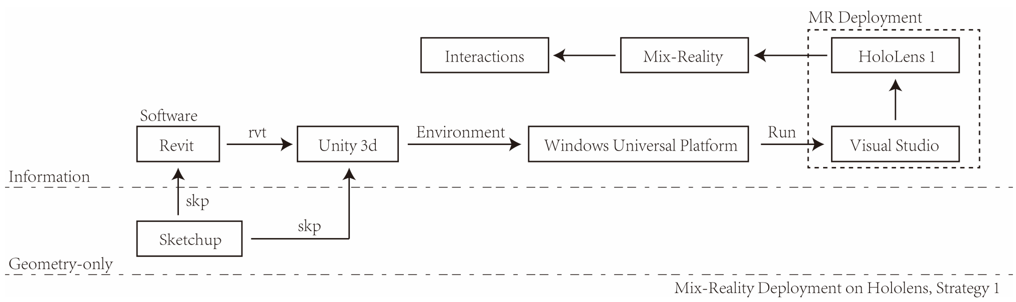


Figure 4.2 d: Establishment of Gamificative Environment

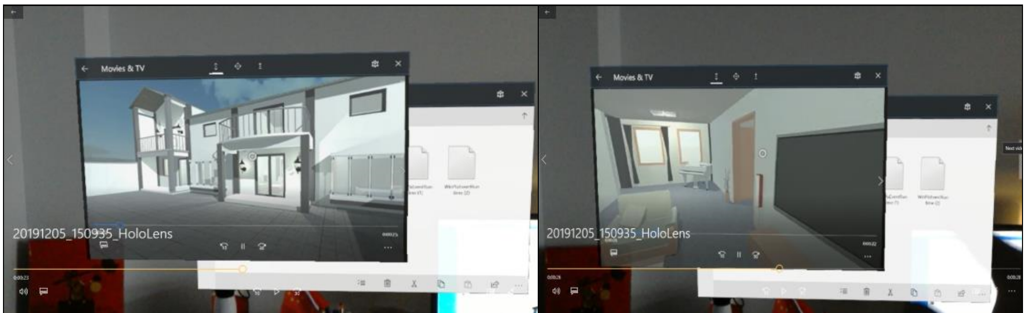
Therefore, for improving the immersive experience during the visualization process, the first generation of HoloLens has been used. HoloLens is a Mixed Reality Technology, with inherited characteristics from both Virtual Reality (VR) and Augmented Reality (AR). Since HoloLens is still under development, the interaction between people and model is limited. The model was deployed to HoloLens via Microsoft Visual Studio. (Figure 4.2.d) shows the process of establishing the gamificative environment for visualization, (Figure 4.2.e) shown scenes from the HoloLens emulator, and (Figure 4.2.f) shows the scene from HoloLens for design visualization. However, due to technology limitations, the environment only shows the VR characteristic rather than MR features. Although the view from HoloLens in this experiment is not sufficiently interactive, it provides an immersive environment for design visualization.

View 1	View 2

View 3	View 4

Figure 4.2 e: Scenes from HoloLens Emulator

Since the first generation of HoloLens is not sufficiently sophisticated, there is limited capacity for interaction and establishing a comprehensive immersive environment. Through the projected video from HoloLens, the design team is able to visualize the project via hologram. Compared with visualization via desktop screen, a hologram via HoloLens is a more attractive way of reviewing the design project. (Figure 4.2.f) shows various scenes of the project through holograms via HoloLens. Although the hologram is presented in the form of a video, it is sufficient for visualization during the project review and assessment process.



HoloLens View 1	HoloLens View 2

Figure 4.2 f: Scenes from 1st Gen HoloLens (Kapogiannis et al., 2020)

Through the integration of Unity3D and first-generation HoloLens, this experiment creates an interactive and immersive VR-based gamificative environment for providing visualization for project design and evaluation. The problems of traditional visualization have been solved through the proposed method via providing a more comprehensive, interactive, and immersive environment. With improved visualization, more details are explored and assessed to ensure all spatial and functional design meets expectations. Hence, this is one of the project's success factors.

Impact 3: Organize the Data Access.

One of the problems in building design is that design data cannot be efficiently accessed by clients to facilitate decision making, resulting in delayed project assessment for relevant modifications. The traditional way of accessing data is through printed documents and off-line presentation, which is time consuming in terms of binding, printing, and arranging stakeholder meetings. Also, stakeholders do not have timely access to design outcomes. Therefore, the traditional method of accessing data, commonly used in current building design, is inefficient. Inconsistences arise from stakeholders not having the most up-to-date information and, due to the large number of people involved in building projects, this poor information accessibility causes chaos, potentially leading to failure of the project.

Timely discussion is important during building project development to avoid the design taking an incorrect direction, and it enables prompt modification for speeding up the delivery process. Timely discussion is enabled through the various participants having access to the same information at the same time. ISO 19650 (2018) regulates that the data need to be centralized for increased accessibility, since decentralized data cause inconsistency. The proposed conceptual framework includes the features of ISO 19650 regarding management of data accessibility. In this experiment, the problems of data accessibility have been successfully solved due to the adoption of the concept of Common Data Environment (CDE).

ISO 19650 requires all data to be stored and delivered via the Common Data Environment (CDE) during the information management process (ISO, 2018a). This research has adopted CDE platforms to carry all data development and coordination; data accessibility is designed for communication both within the design team and with stakeholders. The technical solution to establishing the CDE uses Nuts Clouds to centralize the building design data for access by the design team. Nuts Clouds is accessed via PC, Linux, MacOS, IOS, and Android terminals, which cover most operating systems. Live sync is available in this technology for guaranteeing that all data accessed are up to date. From the proposed solution, the design data can be accessed from anywhere for development and evaluation.

In this technical process of data accessibility management, the design team can efficiently access the data without the restrictions of time and location, and stakeholders can access the data via the shared links and Quick-Response (QR) code. Although data accessibility is improved through this experiment, in comparison with traditional methods, due to the limitation of technology, data access from the client side is still not ideal. Therefore, this is the limitation identified by the research, which needs to be improved in future research.

Due to the restrictions of the current CDE, in addition to using CDE for information coordination, this experiment also chooses to use Instant Messages (IM) as a way of establishing real-time communication within the design team and with stakeholders. Via IM tools, the data from CDE can be conveniently shared and delivered to stakeholders. The IM chosen by this experiment is QQ and WeChat because they are widely adopted in China. Multiple functions have been embedded in these two IM tools to support many activities during building design development. According to observations from the communication between design team and stakeholders in IM, stakeholders can easily access the design data, and the visualization output from the gamificative environment delivered to stakeholders via IM-embedded CDE impacts the understanding of project design.

Data need to be archived once the project is delivered; ISO 19650 (2018) has argued that data need to be removed from CDE and be stored in a safer place for long-term archive. Traditional data storage methods are unregulated; therefore, random data storage will likely cause loss of data. The proposed conceptual framework has adopted regulations from ISO 19650 for long-term data archive in a much-secured way for later access. The project has two backups in different cloud drives and another two backups in HDD and DVD M-disks. Therefore, the data is unlikely to be lost during the long-term building operation cycle. For the delivery process, the proposed solution of this research is both hardcopies and e-copies, since hardcopies are mandated by the national building code. The delivery of e-copies is through shared links via CDE to IM, in DWG and PDF format.

Project participants during the design development have access to building data in an organized way due to the adoption of Common Data Environment (CDE) under the criteria of ISO 19650. Data are accessed from different locations with up-to-date information, and stakeholders can review the data through IM via the shared links from CDE. No data is lost during the project development. Therefore, the research considers that the adoption of the proposed conceptual framework has impacted data accessibility during information coordination.

Impact 4: Management in Data Exchange

In common with most building design projects; this study involves large amounts of data exchanged during each stage of the design development. These data include but are not limited to: 2D drawings, 3D models, rendering images, videos, etc. An efficient method of data exchange is required to ensure the process can proceed efficiently. Using the traditional method, there are very limited solutions to date exchange in project development because there are few regulations that concern this issue. Disorganized data exchange causes inconsistency in file format and software version, which will cause chaos during project development. For example, higher versions of RVT files cannot be opened in lower versions, Unity3D can only read FBX files, and DWG files need support from external applications. The process in this project is considered as successful due to the management of data exchange in information production and visualization development.

ISO 19650 (2018) regulates unification of software versions through the EIR development process, where clearly defined requirements offer a reference as to how different types of data need to be integrated. In this experiment, all the data are managed according to the regulations of ISO 19650 and prepared using Universal Modelling Language (UML) to define the relations between each element. (Figure 4.2.g) shows the structure of the data exchange of this intervention, which is classified into four levels: design level, outcome level, interface level, and visualization level. This structure covers software adoption, data production, information integration, and delivery process, and specifies how each type of data is coordinated and impacts each other.

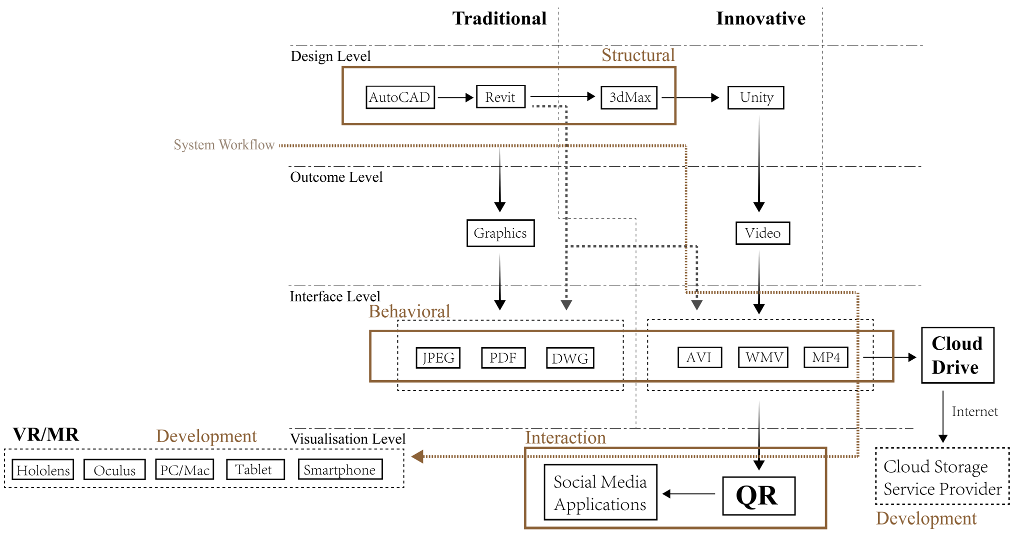


Figure 4.2 g: Structure of Data Exchange in Intervention Study 1 (Kapogiannis et al., 2020)

Each level has specific purposes during project development because ISO 19650 requires clear tasks regarding information flow. The Gamificative environment is highly dependent on the coordination process of different design and modelling tools. At the design level, a 2D-based design document is further developed into a 3D information-based model. This process requires data coordination between different software, with each software having individual roles and functions; therefore, data coordination requires the following of specific procedures. At the outcome level, graphics, images, videos, and other data types are generated based on the established model for the design review and discussion. Different types of data have different usages during the design review; therefore, selection of the most appropriate data type can help to increase reviewing efficiencies. At the interface level, these data types need to be exchanged for integration purposes, so different formats are generated for further process and development.

The framework is divided into four different parts: structural, behavioral, development and interaction, according to the specifications of UML. The structural part focuses on the information development itself; the behavioral part on the data exchange; integration focuses on the data delivery process; and the development part focuses on how to deploy the data in each terminal for final visualization.

The structured data exchange provides a reference from design to establish a gamificative environment for visualization and evaluation. The clearly stated process offers guidance to the design team regarding how to produce, integrate and exchange data. The traditional and innovative methods of data exchange are labelled in (Figure 4.2.g), where it can be seen that traditional data exchange is limited in supporting project development while innovative data exchange through the proposed conceptual framework provides a much more comprehensive process with more types of data exchange formats. The position of the CDE has also been stated in the process for supporting data storage and exchange.

Interrelationship and Thematic Analysis

This study has used a small residential house to assess the impact of the gamificative environment on the coordination of design information. The evaluation is mainly focused on whether the interactive environment can improve the understanding of project design for supporting decision making. Four aspects are taken into consideration to assess whether information coordination is increased, which are, Data Sufficiency and Accuracy, Data Visualization, Data Accessibility, and Data Exchangeability. The results show that by using gamificative technologies, the understanding of project design is improved by the interactive and immersive environment; thus, functional coordination and spatial coordination are increased, and hence improved understanding. Therefore, business performance is enhanced by efficient decision making.

This intervention in action research uses the proposed proposition to conduct the implementation of the BIM paradigm during project development. The project is successfully completed within about three weeks (from July 25th, 2019, to August 16th, 2019) to make the decision regarding the conceptual design stage, which is relatively fast compared to other similar projects. Clients are happy with the design outcomes, and they have good understanding of the project design. This intervention analyses why the project is successfully implemented through the impact of the proposed solution on factors of information coordination. The analysis of the information coordination focuses on four parts: data accuracies and sufficiency, data visibility, data accessibility, and data exchangeability, which interprets in detail why the features in the proposition can impact on these factors to improve information coordination.

The core aspect of information coordination is to ensure that everyone in the project accesses the same information, which means the information needs to be centralized. Therefore, the Common Data Environment (CDE) is the foundation for establishing collaboration and coordination during project development. Once the information is centralized through the CDE, the next step is to ensure that the data is accurately and sufficiently produced. LOD 350 provides the guidelines specifying the level of detail required for each building element because the quality of the graphical model is the foundation for the gamificative environment for immersive and interactive visualization. The structure of data exchange is very important during information production and integration because a project uses a large amount of data in exchange processes, and not just a single file format.

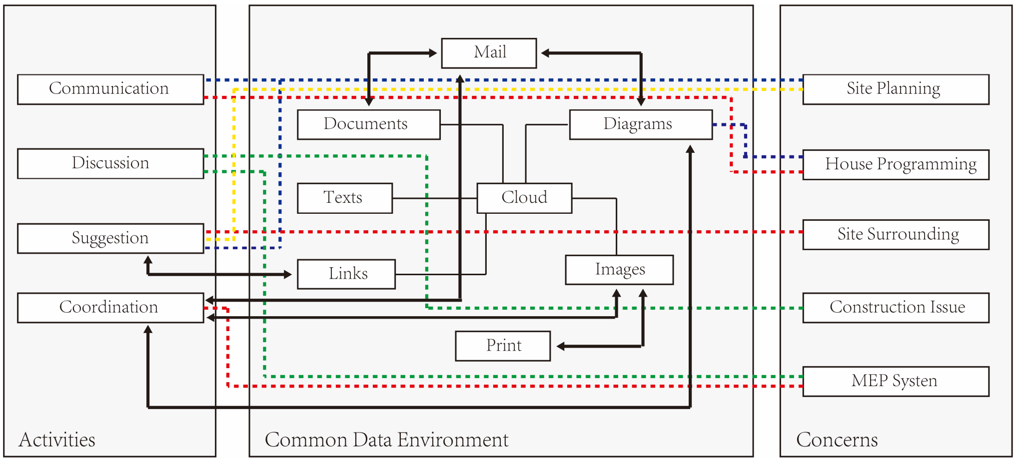


Figure 4.2 h: Interrelation of Communication with CDE in Intervention 1 (Kapogiannis et al., 2020)

According to the data analysis from communication between clients and design teams, eight interrelations have been identified, shown in (Figure 4.2.h). There are four major perspectives, and five concerns are identified according to the findings from the communication analysis, which are listed in (Figure 4.2.h). From each aspect of the activities, there are interrelations established with those perspectives listed in the relevant part. The role of the Common Data Environment (CDE) is to provide an online platform to establish communication via the sharing of documents, diagrams, images, text, and links. According to the findings, elements in the CDE are associated with aspects in the activities to address the concerns. Hence, the observation and analysis from this scenario shows the importance of the CDE because it establishes the bridge between the design team and clients during building design development.

The technology adopted to create a gamificative environment in this project uses Unity3D and the first generation of HoloLens. Unity3D converts the 3D information model from Revit into an interactable visualized environment for the user to have a comprehensive view of the project design. Through the integration of building elements using LOD 350 and ISO 19650, the coordination is successfully addressed in 3D integration aspects through structured data exchange. Support from CDE technologies enables the design team and stakeholders to access the design information in a timely manner. Hence, the identified five factors of information coordination are all positively impacted by the proposed conceptual framework.

However, there are limitations due to the technical implementation in the experiment, which mainly focuses on CDE and interactive technologies. The CDE adopted in this experiment can store the data and provide simultaneous access from different locations, but it cannot provide a platform to directly visualize the data because it relies on local software to perform the relevant tasks. The adopted CDE is more similar to Cloud Drive than an integrated platform to carry out production, visualization, and coordination. Furthermore, due to the limitation of deployable solutions, the visualization in the first generation of HoloLens is not sufficiently interactive, in only providing VR features.

Despite the limitations from a technical aspect, the proposed conceptual framework has provided clear guidance for people and process regarding project implementation. In general, the project is considered successful because clients are satisfied with the design team and the decision-making cycle for conceptual design is less compared with other similar projects, which means those factors of information coordination are positively impacted. The listed impacts are shown in (Table 4.2.b).

Table 4.2 b: Identified Impacts from Intervention Study 1

	LOD 350	ISO 19650	Gamification
Data Accuracy	√		
Data Sufficiency	√		
Data Visibility			√
Data Accessibility		√	
Data Exchangeability		√	

This intervention study in action research uses the proposition through the adoption of a VR-based gamificative environment to conduct the information coordination. The increased data accessibility and data exchangeability through ISO 19650 has improved interoperation between people and data in this scenario, which allows increased manipulation of the produced data. Although the net disk used in this experiment is not exactly the CDE, it plays a role in data storage, access and exchange, which enables the project team to access the data remotely from portable devices. The design information can be shared with stakeholders for review and comments via QR from the net disk through IM, which enables efficient communication and faster decision-making. This project has used a new method of collaboration rather than traditional methods. As discussed through the literature review, productivity is associated with collaboration, and improved productivity can enhance business operation performance (See Figure 4.2.i).

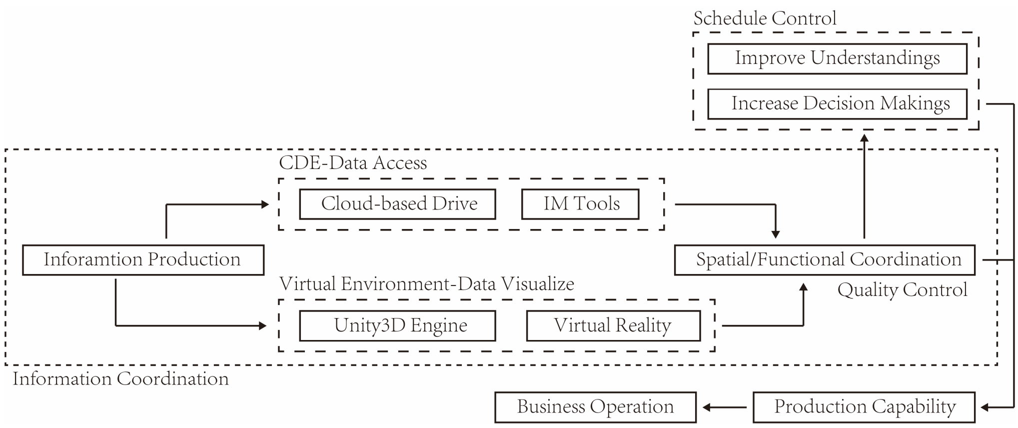


Figure 4.2 i: Impact on Business Operation (Intervention Study 1)

The immersive and interactive visualization environment established through the gamificative environment provides a new way to visualize data, which enables the project team to better understand the design content. This intervention uses a game engine to visualize the data for enabling the interaction between people and virtual environment, then uses HoloLens as a way to create an immersive experience for comprehensively showing the building design, thus providing a holistic understanding of design output for evaluation and assessment. Since viewing the 3D information model in that development software is far too abstract, the game-like interactive environment will help people to understand the 3D environment because it enables a more direct method of viewing the building design from a first-person perspective. With improved understanding, decision making is more likely to improve, speeding up project completion, thus, business performance can be improved.

The adopted specification of LOD 350 has provided a clear reference for constructing an accurate virtual environment for conducting evaluation and assessment. The coordination of space and function is highly reliant on the accuracy and proficiency of data. This case scenario uses the example of a kitchen to produce, develop, and integrate the building elements' data. The accurate shape and size of the building elements helps the design team to better coordinate the building components in the appropriate position. With an accurate virtual model, the gamificative environment can be constructed in a more realistic way for presenting a more effective immersive experience. The project team relies on an accurately constructed virtual environment to decide if further modification or improvement is needed. With a more realistic virtual environment, the digital model in this scenario supports the design team and stakeholders during the decision-making process. Furthermore, the design documents are generated based on the 3D information model in this project, thus the improvement in precision impacts the quality of design delivery. Improved building design quality can help the company to win trust from clients and lead to improved business operation.

Summary of Intervention 1

The induction based on evaluations from the first action show the feasibility of using gamificative technologies to establish an interactive environment for supporting the project reviewal and assessment. The first intervention is using

HoloLens to create a simple immersive environment for visualization, which enables sufficient design information coordination from Data Sufficiency and Accuracies, Data Visualization, Data Accessibility, and Data Exchangeability.

The simplest interactive and immersive technologies improve understanding for speeding up decision making, which can impact on design team productivity to enhance the design company's business operation. However, the first intervention uses the simplest PC-based gamificative technology which, although advantageous in improving project understanding, is limited due to lack of portability and therefore data accessibility. Therefore, the second intervention adopts a web-based gamificative environment, which allows end-users to access the project data via a mobile device without the spatial restriction.

4.2.2 Intervention 2: Office Interior Design

The first intervention study is testing the simplest interactive and immersive technologies in building design to evaluate whether decision making can be speeded up and understanding improved. As expected from the conceptual framework, the results from the first intervention show that the interactive and immersive environment has positive impacts. Despite the feasibility of the gamificative environment, this research needs to test more interactive and more immersive technologies. Therefore, the second intervention is using a different approach to make the same evaluation. The technology adopted in the first intervention requires the running environment of a High-Performance Computer (HPC), and not all project participants have this type of equipment. Hence, the second scenario is creating a more lightweight design reviewing environment that can be operated on mobile devices such as smartphones and tablets.

The second scenario is an interior design project since this is a representative type involving a large number of requirements from clients. Based on personal industrial experience, it is quite hard to make decisions in interior design, for many complicated reasons. A lot of information needs to be coordinated, for example, the type and the color of material, the style of decoration, and the model of furniture. Problems can arise from poor decision-making, poor understanding, and a lack of confidence towards the project design. Therefore, this is a very good scenario in which to test the conceptual framework to ascertain whether gamificative technologies can address concerns.

The most difficult part in this type of project is to satisfy different demands from stakeholders, since office design involves the requirements of many users. The biggest problem is how to enable different stakeholders to understand the project design and come to an agreement. Decision-making is highly related to understanding of the project design, and understanding of project design is impacted by the quality of visualization, according to the findings from the literature review. Since the proposed conceptual framework has the potential to improve the visualization process for improved understanding, and the test from the case scenario has achieved positive outcomes, this scenario uses another type of gamificative technology in a different type of building project to test whether it will achieve the same impact on those factors in the coordination of design information.

This project team consists of the researcher of this thesis (Tianlun Yang), Dr. Georgios Kapogiannis, and the Estate Office of UNNC (Harry Hua). The role of the researcher of this thesis is to perform the entire design, propose technical solutions, and integrate the relevant gamificative technologies into visualization and presentation.

Following the criteria of Robert Yin (2014) regarding case studies, this action research adopts the same approach to evaluate the same factors as in first action. These observations are: whether the Data Sufficiency and Accuracy are impacted by the proposed interactive and immersive technologies; whether the Data Visualization is improved by the proposed technical solution; and whether the Data Accessibility and Data Exchangeability are increased by the proposed environment.

Results from the Experiments

Impact 1: Proficiencies of Design Information

Interior design mostly involves the spatial allocation of furniture, and since an office is designed for multi-functional purposes, it contains many different types of furniture for a combination of usages. With these different types of furniture, it is important to accurately document the specifications from the graphical representative. The traditional method is based on 2D symbol-based drawings, which lacks sufficient detail to present spatial relations of 3D aspects. Therefore, there is limited impact from traditional diagramming methods on spatial coordination. In (Figure 4.2.j.1 and Figure 4.2.j.2) plans of two rooms (Room 320 and Room 423 in UNNC PMB Building) of the project are illustrated to show the insufficiencies of design data. Although the 2D dimensions of each piece of furniture are graphically presented, 3D information, such as the height and shape, is unclear, which will lead to insufficient considerations during the design evaluation process.

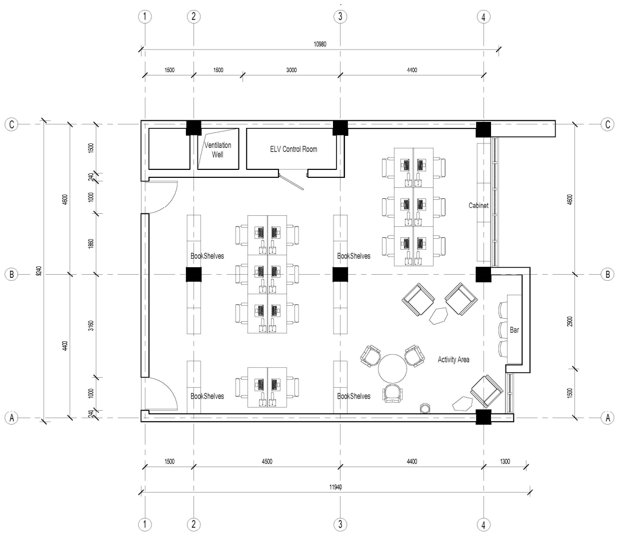


Figure 4.2.j.1 Regular Plan, Room 320

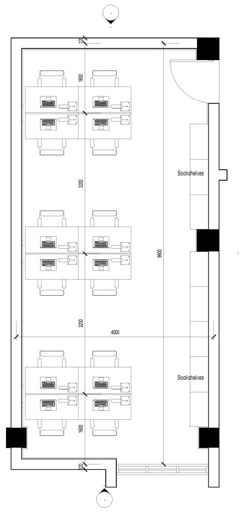
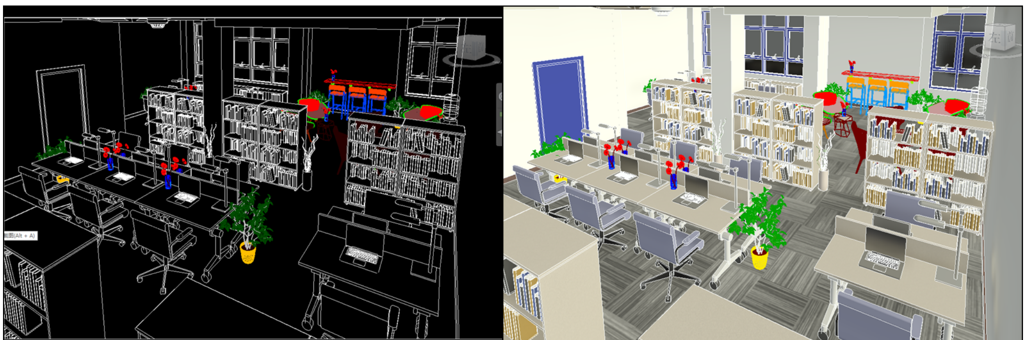


Figure 4.2.j.2 Regular Plan, Room 423

Figure 4.2 j: Intervention Study 2 Plan Diagrams

To improve the insufficiencies in building diagram presentations, this experiment has adopted the proposed conceptual framework to establish the 3D model for spatial coordination of different types of furniture. The project develops the 3D information model based on the 2D preliminarily diagrams, using Autodesk Revit as a modelling tool for constructing the 3D environment. Relevant geometries are imported to Revit from other modelling software via data format conversion. Therefore, all the graphical data of the building components are integrated in a single model for spatial visualization and further development. Different model styles can be outputted from the integrated 3D information model for reviewing. (Figure 4.2.k) shows two different styles from the Revit models.



3D View in Line, Room 320	3D View in Shaded, Room 320

3D View in Line, Room 423 | 3D View in Shaded, Room 423

Figure 4.2 k: 3D Diagrams to Make Spatial Representation

Impact 2: Interactive and Comprehensive Visualization

Although 3D information modelling under LOD 350 can provide the design team with a better reference in spatial relation to avoid potential clashes, it is too complex for other stakeholders to understand. Therefore, stakeholders need to have a view based on outputs from a 3D information model through images, videos, and other media. The traditional way to represent design is using rendering images, and these images are established via additional, inaccurate 3D graphical models, which sometimes do not correspond with the 2D design diagrams. Such inaccurate information will lead to misunderstandings by stakeholders, and thus delay the decision-making process.

According to the proposed conceptual framework, all the outputs of the design need to be based on the established 3D information model. Therefore, all the required plan drawings and rendering images are produced through a single model for ensuring the consistency and accuracy of design information. (Figure 4.2.l) shows the renderings from the 3D information model; the spatial relation between each building element is aligned with other 2D diagrams.

Rendering of Room 320 | Rendering of Room 320

Rendering of Room 423 | Rendering of Room 423

Figure 4.21: Renderings from 3D Information Model

However, as stated in the first case scenario, static images cannot provide a comprehensive view of design data because multiple images are required to present a single point in design. Therefore, a more immersive and interactive way of design visualization is required for stakeholders to improve their understanding of project design. To improve visualization, this research firstly adopted a new technique in current state-of-the-art technology in the AEC industry, which is Live-Rendering. The Live-Rendering engine used is Enscape3D, which can be integrated with a 3D information model produced by Autodesk Revit. The rendering engine can real-time sync with the Revit model to create photo-realistic images.

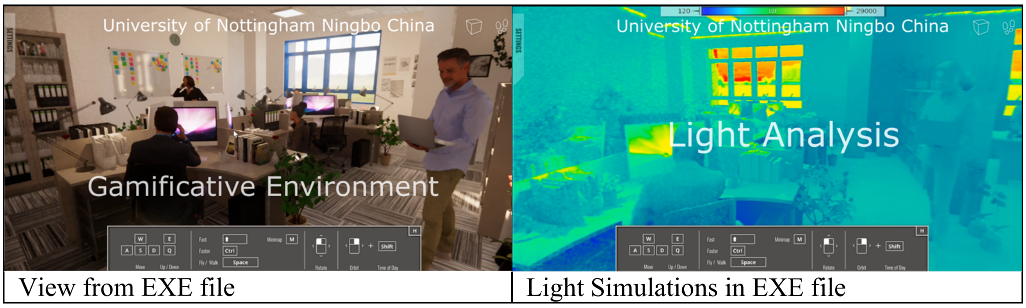


Figure 4.2 m: Real-Time Renderings and Simulation

Live-Renderings can be achieved through exporting a 3D information model to rendering engines. Through the exported executable file, no additional software needs to be installed on the PC, and the application can be run directly to present the design model. (Figure 4.2.m) shows the screenshots from the EXE file. In such an environment, people can act first-person to explore each detail in the building. Beyond visualization, simulation of the light can also be conducted to make the relevant assessment. Hence, a comprehensive visualization environment has been established.

However, although the real-time rendering has created an interactive environment, it is still not immersive enough for design visualization. Also, the running of executable files still requires access to the local file, and still requires certain performance of the computer to operate. Based on the personal experience of the researcher, clients and stakeholders normally do not have any relevant design software to support the running design model directly, while the running of design software requires high-end computers. Therefore, this research has found a further solution by using Panorama outputs from a real-time engine to create a static image-based interactive environment. (Figure 4.2.m) shows the interactive environment being stablished by using Panorama-based images. Based on the 2D floor plan from the 3D information model, the project has spotted different positions in the sandbox (Figure 4.2.n).

Figure 4.2 n: Scenes from Panorama-based Interactive Environment

Instead of presenting the holistic model via the executable file, this research proposes a new solution for minimizing computation pressure for illustrating the design model. The solution is named "Static Image-based Dynamic and Interactive Illustration Method" by this research. In principle, this solution is based on the Panorama images output from rendering engines, because from a rendering engine it can achieve the same visual effects as the regular rendered images. By using the technical principle of making movies, a dynamic motion consists of multiple static images; therefore, by integrating multiple Panorama points from the model, a dynamic interaction can be made. 720Yun is the chosen platform to integrate multiple Panorama images for holding this dynamic environment.

The environment includes the sandbox plan of the office, where multiple points are selected for presenting different angles of views of the project design. The arrow on the ground can link different Panorama views together between each adjacent viewpoint. Through such an environment, both design team and client team can have a comprehensive understanding of the project, which can subsequently lead to effective assessment and evaluation to support the decision-making process. In this way, pressure on IT computation can be minimized and data accessibility improved. Therefore, the entire experience of the design delivery is enhanced.

Figure 4.2 o: Scene of the VR View of the Project

Design data can be accessed via mobile application, and through the mobile device, the application can support the VR mode through wearable headsets. (Figure 4.2.o) shows how the VR environment looks. The VR will create an immersive visualization environment for conducting a more comprehensive design assessment. Through the VR environment, interaction between different Panorama scenes can be made by pointing the center cross to the arrow on the floor. See the (Figure 4.2.p) for detail. Therefore, no additional equipment is required to switch viewpoints to explore the visualization.

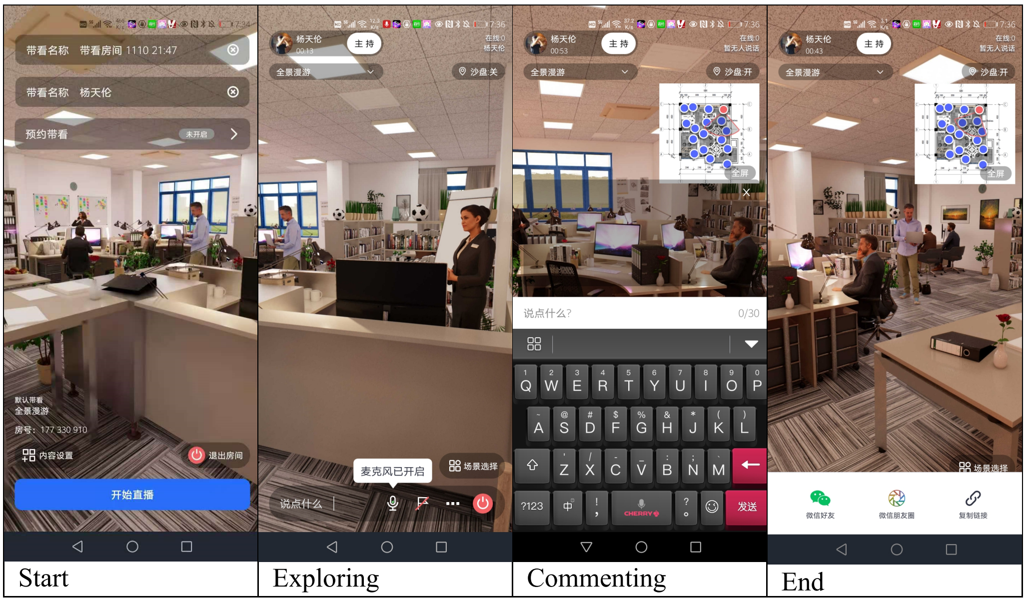


Figure 4.2 p: Virtual Tour through Live Broadcasting

Inspired by live-broadcasting, which is extremely popular nowadays, this research uses similar technologies to enable live-presentation of the design. By using the relevant mobile application, this solution can provide project participants with a platform to view the project with the design manager and provide instant feedback via the platform for discussion. (Figure 4.2.p) shows the virtual tour with interactions (exploring and commenting) presented. Therefore, the interaction between the design team and stakeholders is established via virtual environment.

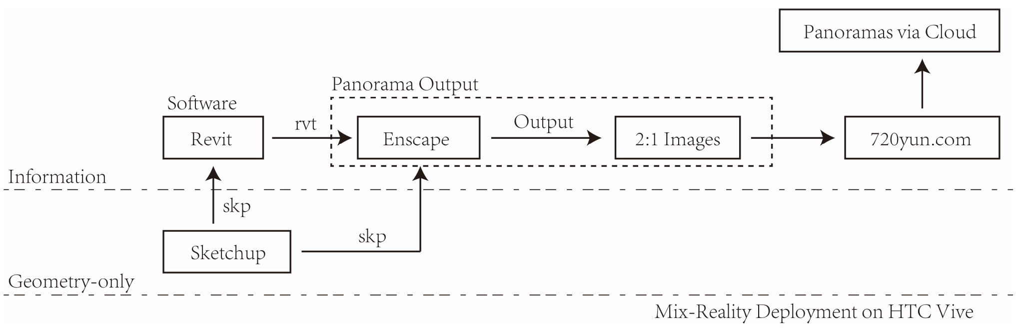


Figure 4.2 q: Technical Process of the Gamificative Environment

The technical process is illustrated in (Figure 4.2.q) for the establishment of the panorama environment. For the virtual tour, the selected technical solution uses an application called Panda Live-Show to connect with the data from 720Yun; both are from the same software vendor. The design manager sends an invitation link to each of the project participants to join the virtual room. Once the broadcast begins, all participants follow the design manager's screen, i.e., they watch what the design manager is doing. Feedback and discussion happen directly in the virtual room, while the virtual tour can be recorded for later review. The advantages of the virtual tour with the design manager are that the concept of the design can be accurately delivered to all project participants, and relevant points can be highlighted. Therefore, the holistic understanding of the project design can be improved.

Impact 3: Online-based Data Accessibility

The established gamificative environment not only allows users to explore each corner of the interior design, but interaction between design team and stakeholders is also linked by the virtual environment. In this project, the project team provides a convenient solution for stakeholders to access the design data to view the visualization outputs.

The limitation in the traditional method is that a portable drive or online transfer is required to deliver the data. Although online transfer can deliver the information in a timely manner, due to its capacity limitations, large files are not easily delivered, especially when large amounts of content need to be visualized. Therefore, the visualization outputs cannot be efficiently viewed by stakeholders, which will likely lead to delays in decision making. ISO 19650 (2018) regulates that all data need to be processed via a common data environment from production to delivery. Due to the limitations of this technique, there is no single available CDE that can achieve the entire process; therefore, multiple tools need to be used together during project development.

720Yun is adopted as an online platform because it not only carries project data, but is also a very good tool for integrating Panorama images to create the 360-degree environment through the web-browser and mobile app. The application is free to access with adequate supportive functions for design assessments. In this way, design teams have a tool not only to present but also to deliver the created Panorama images, therefore, its role as CDE is important in accessing the information.

This project has successfully delivered the visualization of the project design to stakeholders. The content from 720Yun can be directly shared via either links or QR code through daily use of IM applications, which allows design team and stakeholders to access the information at any time and from anywhere. The group chat function in IM also plays a role in supplementing the CDE, because through the group chat, a single message can be distributed to everyone in the group for access, while everyone in the project is involved in the group chat. Therefore, it allows the design content to be efficiently delivered for assessment and feedback.

Impact 4: Allocation of Data Exchange

The visualization process through the establishment of a gamificative environment requires significant exchange of data throughout the project development because multiple software and tools are used, and each software uses a different file format. The most difficult problem is not focusing on how to use these files but on how to integrate the files.

Due to the limitations of technical solutions in traditional design development, few data formats need to be exchanged because not much software is used. The gamificative environment involves a large amount of data, such as 2D drawings, 3D modelling, visualization outputs and online interactivity. Therefore, the exchange of data needs to be planned to avoid chaos.

ISO 19650 (2018) regulates how the information needs to be developed, requiring a clear EIR and BEP. Exchange Information Requirement (EIR) defines how the project meets with all the requirement at an organizational level and project level as regards what information needs to be produced and what data to be exchanged. Followed by EIR, BIM Execution Plan (BEP) plans how information is produced during the design development.

Data exchange has three stages in this experiment: production, visualization, and delivery. The production stage discusses how building data are constructed and integrated for establishing the gamificative environment for visualization and interaction purposes; the visualization stage discusses how established 3D information models are viewed; and the delivery stage discusses how design information can be accessed by different project participants through different platforms.

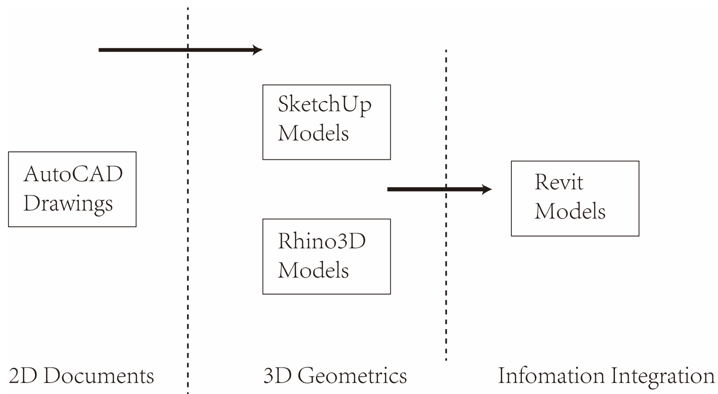


Figure 4.2 r: Data Exchange for Model Development

With the combination of different modelling tools, the information cascade of producing the 3D information model in this case scenario is shown in (Figure

4.2.r); the DWG format of 2D drawings is imported to 3D modelling software for developing the geometries, while the format of 3D models includes SKP and 3DM, which is imported for further development in Revit for information modelling. With the integration of these data, LOD 350 is reached, increasing the information coordination for data accuracy and sufficiency. From 2D to 3D and then to a 3D information model, each step is required to exchange the data. According to ISO 19650 (2018), it is important to select the most appropriate tools to process the relevant data for ensuring these data can work with each other. Therefore, during IT mobilization, this experiment has carefully examined whether the data format can be read by subsequent software.

Once the 3D information model is established, the next step is to visualize the design content. (Figure 4.2.s) shows the data exchange process for visualization development. Beyond the static images, Live-Rendering is used in the form of EXE files to increase interaction. Virtual Reality is used for increasing the immersive experience, and Panorama images are produced from a Live-Rendering engine for online deployment. The information cascade (Figure 4.2.s) clearly represents how data are exchanged to impact the visualization. Each visualization solution is used at a different stage of the project development.

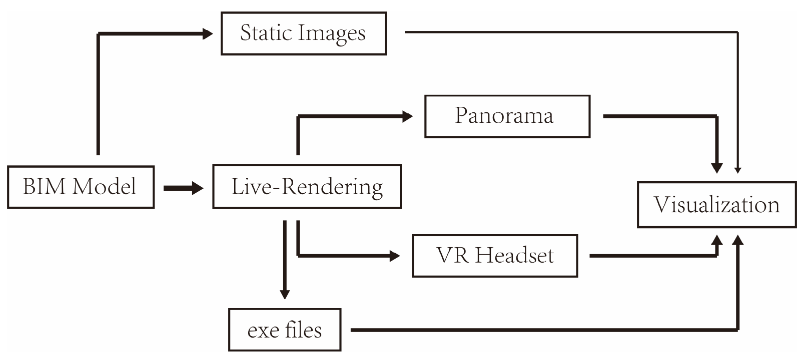


Figure 4.2 s: Data Exchange from Visualization

The data exchange for information delivery is shown in (Figure 4.2.t), which shows how interaction is established between PC and mobile devices for accessing the same design information for visualization. The output from the 3F information model, such as Panorama, and 2D drawings are stored in the Cloud terminal, from which the files are shared via a link and QR codes to social media. Since social media is normally operated from mobile devices, the data are interrelated between both PC and mobile devices. However, although the solution has solved the interactive and immersive visualization issues for design evaluation, the feedback communication is still based on the additional IM application. Therefore, a more efficient way to provide real-time feedback is required.

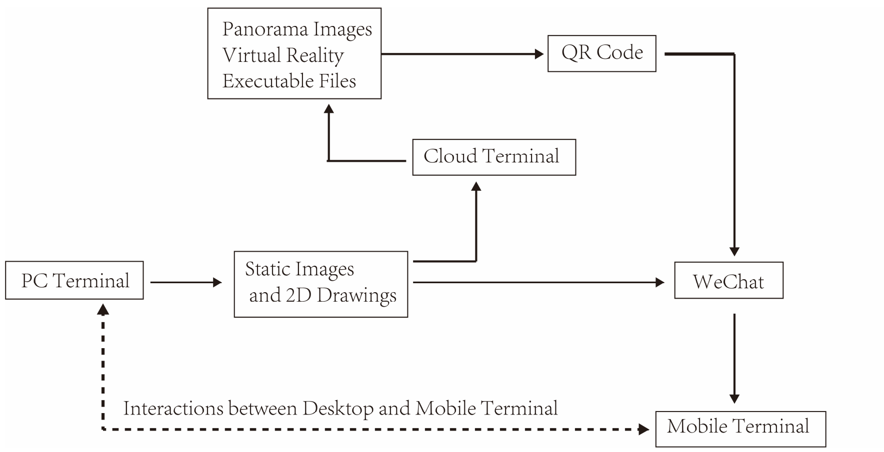


Figure 4.2 t: Data Exchange for Design Delivery

The data exchange process is deliberately considered during project development, and this process follows the requirements of ISO 19650 regarding the EIR. The proposed conceptual framework inherits the features of ISO 19650 for implementation in the BIM-driven project, which organizes the structure of data exchange in three key stages. Since there are no regulations regarding the data exchange process, the proposed conceptual framework provides a guideline for how the information needs to be developed, integrated, and delivered, which impacts the information coordination for the data exchange process.

Interrelationship and Thematic Analysis

The second intervention is to keep testing the role of gamificative environment based on the findings from first intervention. In the first intervention, the simplest interactive and immersive technology was tested, and the results show that such technologies can improve understanding to increase decision-making. The second intervention uses a different approach of interactive technologies to allow end-users to access the project design via cloud through mobile devices. The findings from evaluation show that the impact of the technical approach in the second intervention is the same as the technical approach in the first intervention. Moreover, as more cloud-based information containers are applied, the gamificative environment created in the second action enables more efficient decision making due to observation and communication during the project design. Hence, the general conclusion from the second action further supports the feasibility of using an interactive and immersive environment to enhance project performance.

This design project was successfully completed between 18th June, 2020 and 19th August, 2020. The design of the three office rooms took around two months, while the design period of the first two rooms (Room 320 and Room 423) was from 18th June, 2020 to 2nd July, 2020 - around two weeks. For the Room 416, due to the complexity in function, extra time was required. Overall, the design is very efficient, and stakeholders fully understand the design content as regards furniture, materials, and utilities. This research discusses why this project is successful, focusing on how the proposed conceptual framework impacts each factor during information coordination. In this experiment, the research has tested another technical solution in a gamificative environment, which also successfully lead to the project completion. Four factors are interpreted in detail regarding data accuracy and sufficiency, data visibility, data accessibility, and data exchangeability to objectively explain how the proposed conceptual framework impacts information coordination.

Through the systematic evaluation, this research has found that through the adoption of a cloud-based Panorama environment, the data can be well-stored and well-accessed for building design development. The cloud database allows project participants to access the building design in a very convenient way for conducting the assessment and evaluation. The Panorama-based visualization enables creation of a dynamic and interactive environment based on the static-images. Such visualization solutions do not require much computational power of devices, which allows access to data from almost every available device (e.g., cell phones, laptops). Based on these static images through online data stream, a VR environment from mobile devices enables better understanding of the design by the project team, without further use of extra VR devices.

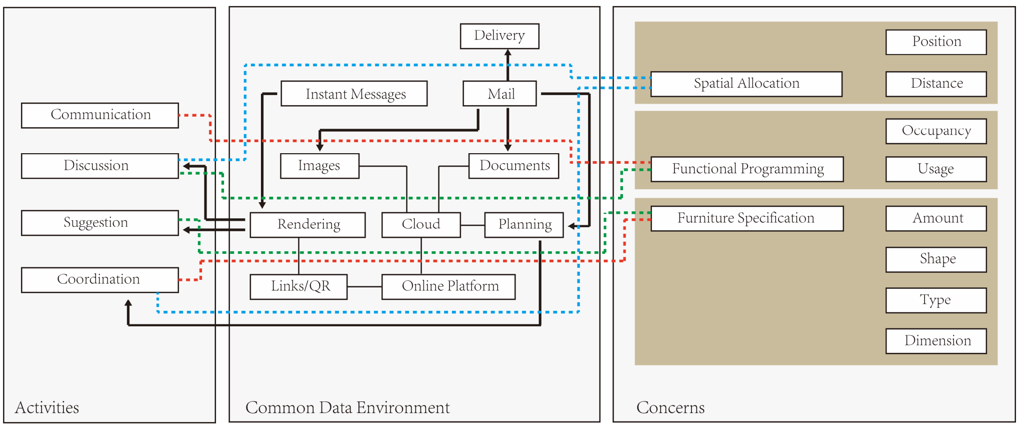


Figure 4.2 u: Interrelation of Communication with CDE in Intervention 2

Findings from the analysis of communication data between design team and stakeholders are presented in (Figure 4.2.u). There are three parts of the finding structure: activities, CDE, and concern. There are three major concerns identified through the data analysis, which are, spatial allocation, functional programming, and functional specification. With further exploration of the communication data, spatial allocation is categorized as position and distance; functional programming as occupancy and usage; and functional specification as amount, shape, type, and dimensions. The interrelation between activities and concerns are established (Figure 4.2.u). Moreover, the findings show that the content in CDE is connected with aspects in activities for addressing the issues of concern. Hence, the CDE plays an important role in providing instant accessibility of the produced data.

According to the evaluation during experiment, the accuracy and quantity of a 3D information model are required for establishing the gamificative environment for offering visualization. Without an accurate model in sufficient detail, the gamificative environment does not have much value in terms of design evaluation. The online database (or centralized database) can enable the project team to efficiently manage the building design data because the data can be shared and delivered via exchangeable links. Hence, no portable storage devices are required for transferring the data, which saves time. The dynamic environment based on static images can help project teams to visualize the design, and enables project participants to access the design data from different terminals.

The impact of the proposition on each factor of information coordination is listed in (Table 4.2.c). During the implementation of the conceptual framework, the features of LOD 350 impact data accuracy and data sufficiency; the features of ISO 19650 impact data accessibility and data exchangeability; and the feature of gamification impacts data visibility. Therefore, the quality of the 3D information model impacts the gamificative environment and the quality of the gamificative environment impacts visualization and interaction, which supports the findings from first intervention study.

Table 4.2 c: Identified Impacts from Intervention 2

	LOD 350	ISO 19650	Gamification
Data Accuracy	√		
Data Sufficiency	√		
Data Visibility			√
Data Accessibility		√	
Data Exchangeability		√	

In this project, through the technical adoption of a Panorama-based gamificative environment, the proposed conceptual framework impacts design delivery. Although this is not a commercial case, not involving any profits, information coordination still impacts the method of collaboration and decision-making through coordination of building design information. In this scenario, the cloud-based presentation environment allows the project team to conveniently deliver the design content to different stakeholders via QR and links. The static-images based dynamic and interactive environment allows mobile devices to run the design content without relying too much on hardware performance. Therefore, the data can be accessed from almost any platform without the restriction of location. Furthermore, with the support of live-show, multiple people can access the same virtual environment. Thus, the improved accessibility allows increased collaboration and communication. Since collaboration is important for improving the core production capability, and business operation relies on productivity, this scenario (Figure 4.2.v) has provided a pilot study for improving collaboration through a gamificative environment.

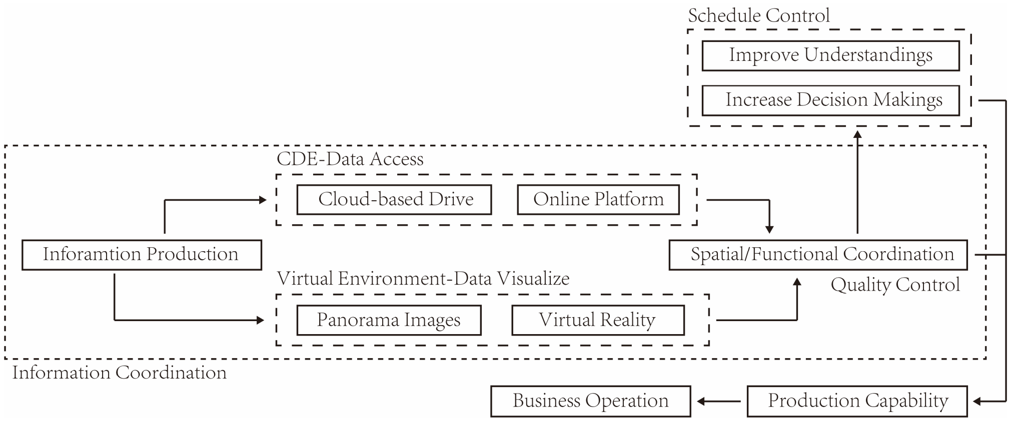


Figure 4.2 v: Impact on Business Operation (Intervention Study 2)

In this intervention, the design team has established a photo-realistic virtual environment for showing the content of the interior design. Although the mobile device cannot provide an immersive environment, with the support of a wearable headset, both an immersive and interactive environment can be achieved via an online cloud drive. The wearable headset is an affordable phone carrier available for everyone, requiring little investment during the IT mobilization. With the assistance of LOD 350 criteria, the detail is constructed for improving the quality of Panorama images output from the rendering engine. Since the dynamic environment is established based on static images, understanding of the design is impacted, thus impacting decision-making. Since decision-making and quality of building design rely on the quality of the virtual environment, LOD 350 plays an important role as it provides a reference for the construction of a gamificative environment from the substantial content - hence the significance of LOD 350 in building design business operation.

The proposition impacts the business operation of a building design company from three aspects, which are, collaboration, the quality of design, and decision making. Based on evaluation during the experiment through case scenario, this research has found that collaboration impacts decision making, and decision-making impacts the quality of building design. Hence, the combination of ISO

1650, LOD 350, and Gamification can impact building design operation, because they subsequently impact information management, quality of data development, and the way of visualizing the project. From these perspectives, the core production capabilities are improved.

Summary of Intervention 2

This research adopts web-based interactive and immersive technologies in the second intervention to create a visualized gamificative environment, which allows project participants to better access the data via mobile devices. This type of gamificative environment is light-weight because the visualization is static panorama image-based, with low requirements in terms of hardware. This means that end-users can utilize their daily portable devices such as cellphone and tablet to review the project design, and comments and decisions can be made in a timely manner, hence increasing design team productivities.

Through the experiment in the second intervention, this research has further provided evidence that an interactive environment in building design can improve understanding of project development for increasing the efficiencies of decision-making. The evaluation and assessment of the first and second interventions show that these technologies enable interaction between people and the virtual environment in an immersive way. However, a more attractive way to increase people's interest is still required and hence, the third action will adopt more state-of-the-art technologies for creating an interactive and immersive gamificative environment for supporting decision making.

4.2.3. Intervention 3: Airport Staff Restaurant

The findings from the first two intervention studies have provided sufficient evidence to support that an interactive and immersive environment can increase the efficiencies of decision-making in building design. However, due to the limitation of previous gamificative technologies, there is insufficient interaction between people and virtual environment. Hence, based on those limitations that have been identified, the third intervention will use more advanced technologies for enhancing the experiences in design review and assessment.

The establishment of interactive and immersive environment requires the support from relevant hardware and software. The first intervention has adopted Microsoft HoloLens, but due to lack of support from software, the created immersive and interactive environment does not meet with expectations of the conceptual framework. Similarly, despite the second action using mobile device-based portable VR headset, there is a limitation in positioning technology to support immersive reviewing. Therefore, the third intervention chooses to integrate with both hardware and software. The scenario chosen by this research is an Asset Modelling project located in Ningbo Airport. The purpose of this project is to provide a feasibility study for digitalization of entire airport facilities. The key to this study is using state-of-the-art technology to support asset management.

According to ISO 19650 (2019), Asset Information Model (AIM) is the foundation of Asset Management System (AMS), which is extracted from Project Information Model (PIM) to support daily management activities for certain maintenance purposes. Since AIM is for facility and asset management, the most difficult part is how to build a valid model based on the existing information. This case scenario deals with how to efficiently develop an AIM for a facility management team through the adoption of the proposition by using a mixed-reality based gamificative environment. This project is successfully developed in an experimental way, to highlight the impact of the proposed solution on factors in information coordination.

The project was a summer research program from July to September, 2020, purely for academic research purposes. The project team consisted of PhD, PG and UG students, led by academic staff and PhD Students. The main team members were: Tianlun Yang (PhD Student), Dezhou Kong (UG Student), Dr. Georgios Kapogiannis, and Prof. Jiequn Guo. The contribution of the researcher of this thesis in this project was proposed solutions (system architecture) regarding to how interactive and immersive technologies is implemented within the standards, methods, and procedures, then do the technical development and integration along with Dezhou Kong and other students. This project was submitted to China National-level Competition of smart construction and won first prize in the University Group.

The successful implementation of immersive and interactive environment by using relevant hardware and software not only shows the feasibility of using a gamificative environment in an asset management project, but also matched with those observed factors in first and second actions. These results are from the systematic evaluation followed by criteria of Robert Yin (2014).

Results from the Experiment

Impact 1: Accuracy in Data Production

The requirement of clients of this project was comprehensive information modelling of the building assets, including architecture components (windows and door), structural components (column and beams), MEP/HVAC system, and the building assets (facilities). The purpose of this project was to establish an AIM model for preparing the AMS in Facility Management. Therefore, the task team were required to build a comprehensively detailed 3D information model containing both graphical and non-graphical information to support the facility management process. This project differed from other building design projects in that it needed to create a model based on the existing assets.

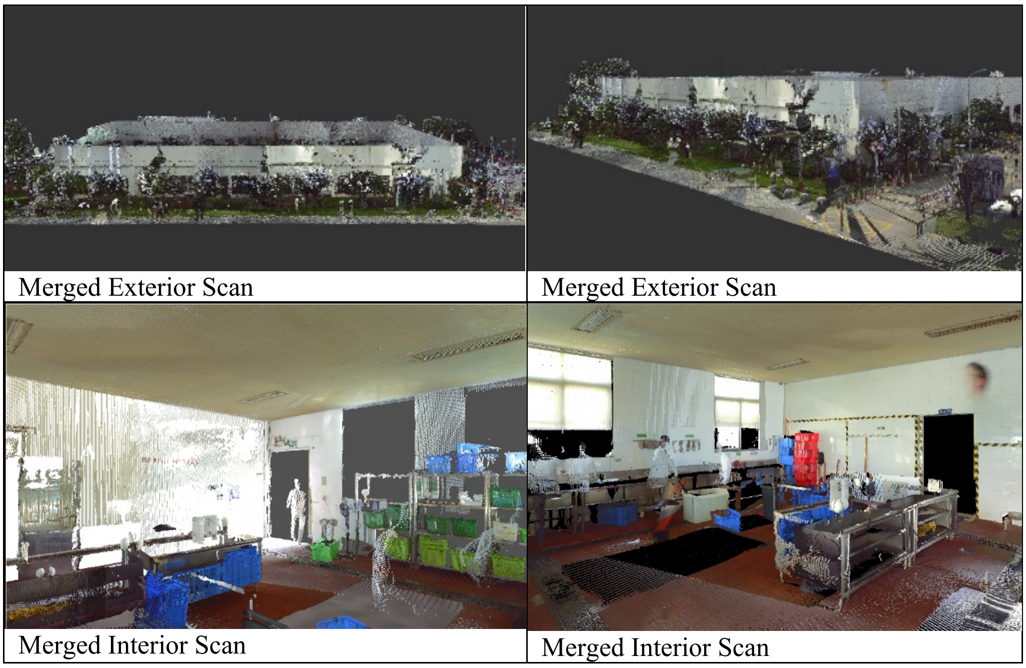
Since the project detail level is very important for establishing the AMS, accuracy and sufficiency of the 3D information model was vital. The problem is how to collect accurate data from the existing assets to support the modelling development. The traditional way of collecting data for asset modelling is through the existing 2D drawings. However, due to the limitations of 2D-based diagrams, the details are insufficient as 2D symbol-based diagrams are limited to LOD 100. Therefore, a more advanced data collection technique is required to collect the essential information for developing the 3D information model to LOD 350.

Laser Scanner | GNSS

Figure 4.2 w: Laser Scan and GNSS Equipment

Due to the age of the building, the only existing data was in the form of paper 2D planning; therefore, the project team used a variety of technology to collect the required data for asset modelling. Precise data is required in order to ensure accurate modelling and therefore, advanced data collection technologies were used, including laser scanning, GNSS, and photogrammetry, aimed at capturing high-quality data for a detailed asset information model. (Figure 4.2.w) shows the laser scanning equipment and GNSS during site work of the data collecting process.

The application of GNSS supplementary to laser scanning is to locate the accurate position for the laser scan data. During the laser scan data collection process, multiple scan points were required for merging purposes, with overlay percentages considered for the combination accuracies. Both interior and exterior data were scanned for comprehensive coverage. Following collection, these data were transferred from laser scanner to computer via an SD card, then processed on the computer through Autodesk Recap. Realistic images were created in Recap for providing reference of 3D information modelling. (Figure 4.2.x) shows the results from the processing of the laser scan data, with exterior and interior merged. The graphical information can be measured for showing the dimensions during the modelling development.



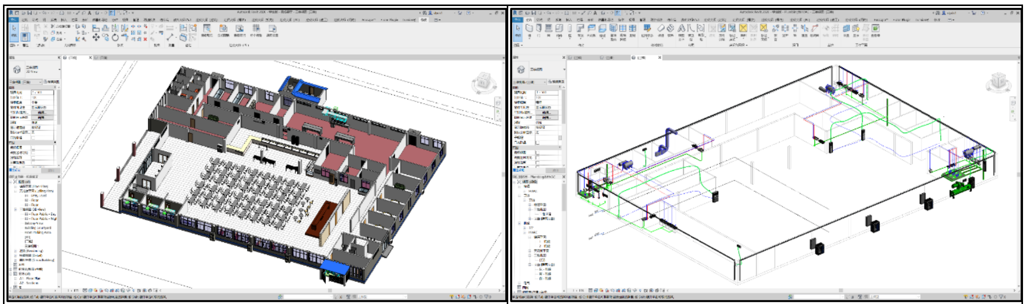
Merged Exterior Scan | Merged Exterior Scan

Merged Interior Scan | Merged Interior Scan

Figure 4.2 x: Scenes of the Laser Scan Processed Data

Based on the processed data from the laser scan via Autodesk Recap, the project team started to develop the 3D information model. The team was divided into different task groups according to the criteria of ISO 19650. Based on the nature of the project, two major task teams were set up: architecture discipline and

MEP/HVAC discipline. (Figure 4.2.y) is from the modelling process of the project development. The tool largely used to establish the 3D information model was Autodesk Revit, since this software can integrate both graphical and non-graphical information. Moreover, Revit has high capabilities in 3D information management.



Modelling of the Architecture	Modelling of the MEP/HVAC

Figure 4.2 y: Information Model in Autodesk Revit

Asset information such as tables and facilities have been added to the information model for the asset statistic and visualization purposes. With the enriched graphical data through adoption of the specifications of LOD 350, the project team can implement the model as a visualization application.

Impact 2: Visualization through Interaction with the Virtual Environment

Once the 3D information model is established according to the reference of collected data, the model is static and cannot sufficiently interact with people through the virtual environment. Traditional asset management uses a 2D-based diagram from as built documents, which is limited in terms of understanding the relation between each of the building elements. The location and position of different building components are not clearly documented through 2D drawings; therefore, the proposed AIM can impact the visualization process to improve facility management teams' understanding of building assets.

The visualization process is based on the graphical information of the Asset Information Model (AIM), with multiple visualization solutions for review and evaluation purposes. One of the most common solutions is use of a rendering engine to output the images. The advantage of rendering engines is that they can either read the model format from the modelling software or as a plugin embedded in the modelling tool. As a result, the original graphical model can be visualized with photo-realistic effects, thus enhancing understanding of the project. (Figure 4.2.z) shows the renderings from AIM, which comprehensively represent both interiors and exteriors of the project. The rendering engine this project uses are Lumion and Enscape3D. Both can directly connect with Autodesk Revit as sync plugin; therefore, rendered images can be quickly generated from the BIM model. Since the engine can directly read the scene in the BIM models, numerous images can be outputted as requested by design and client teams, which enables fast visualization for decision-making process.

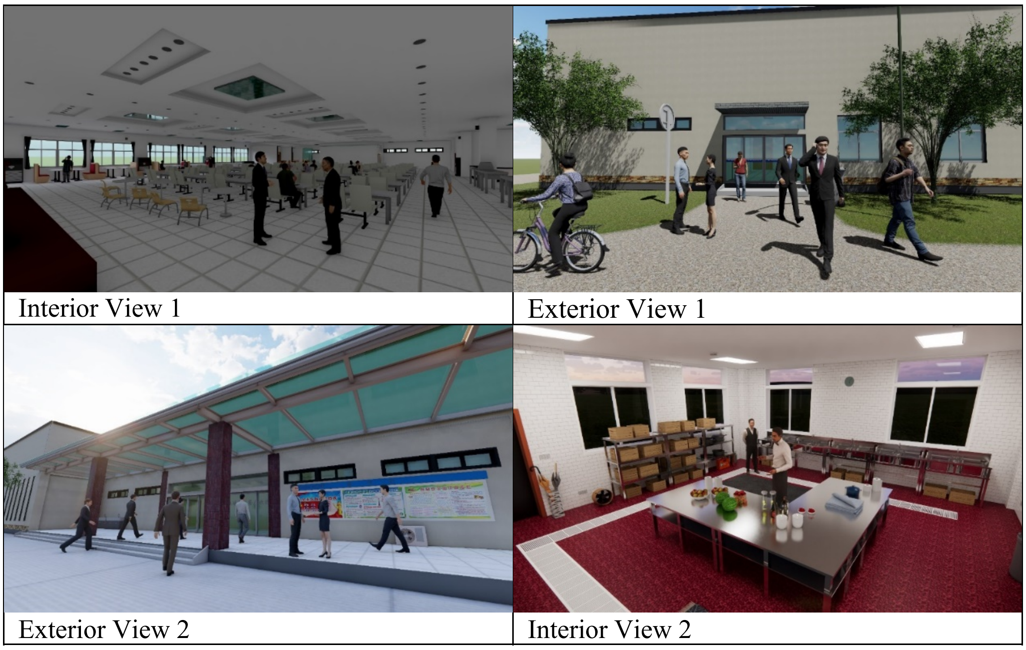


Figure 4.2 z: Scenes from Renderings of Asset Information Model

(Figure 4.2. aa) shows the visualization process from data collection, firstly with the data source via Laser Scanner, GNSS, and Photogrammetry, then based on the processed data, the project team made the 3D information model for conducting analysis, management, and visualization.

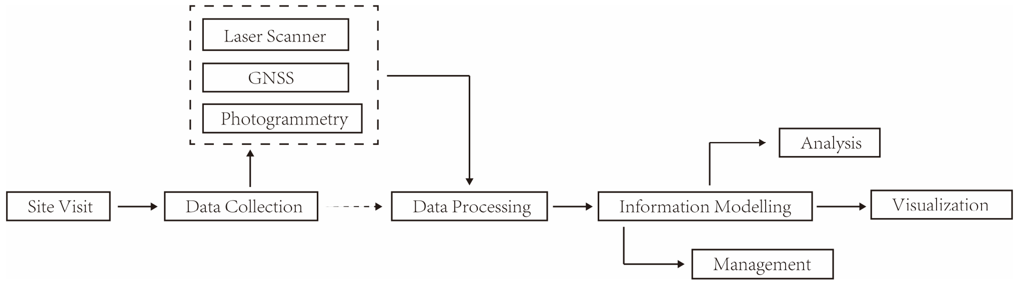


Figure 4.2 aa: Technical Process of Visualization from Data Collection

However, the images represent static views, which cannot comprehensively cover the project model. Moreover, the project team aimed to achieve an immersive and interactive environment for conducting the asset management. Therefore, a more dynamic environment has been used by the researchers in this project for testing the consequential effects. For establishing a more interactive and dynamic environment for increasing the user experience in project development, the researchers decided to adopt a mixed-reality environment to create an immersive virtual environment for reviewing and assessing the project.

Similar with the technologies used in the first intervention study, this project also used HoloLens as the equipment for the mixed-reality environment. (Figure 4.2.bb) shows the technical process of mixed-reality deployment. The HoloLens used by this project is second generation, which is supported by more applications for creating the hologram environment. The hologram images provide sufficient interaction to enable people to play with project models in a virtual environment, which can subsequently create a gamificative environment for the development of the project. According to criteria of ISO 19650 (2018), all data need to be processed in a Common Data Environment (CDE), and the CDE used by this research is Trimble Connect, which is an integrated collaborative environment for reviewing project graphics and models. Also, via this CDE, holograms can be deployed in HoloLens 2 for project reviewing.

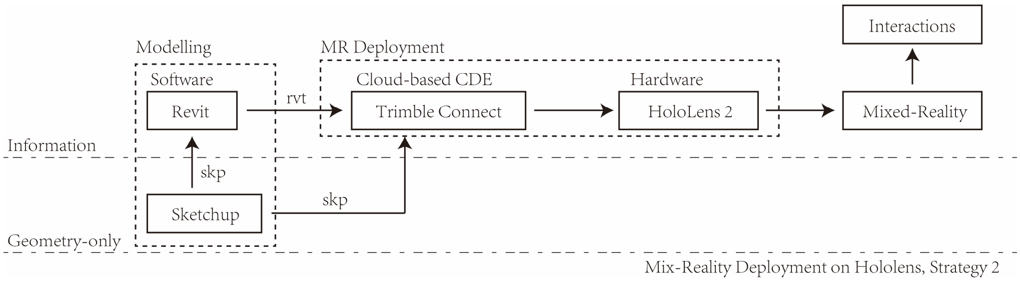
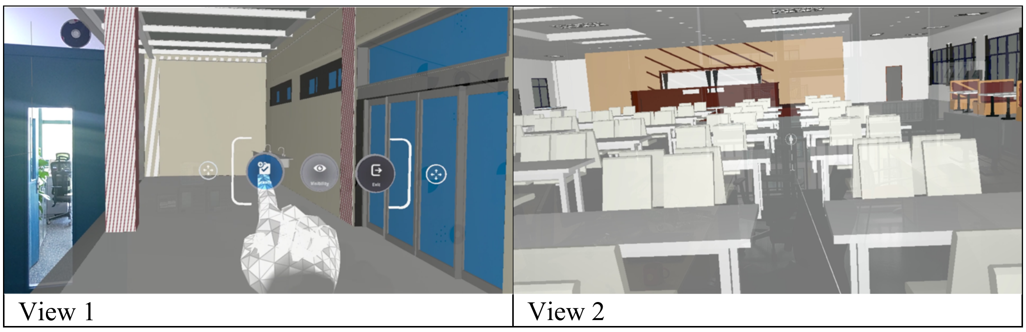
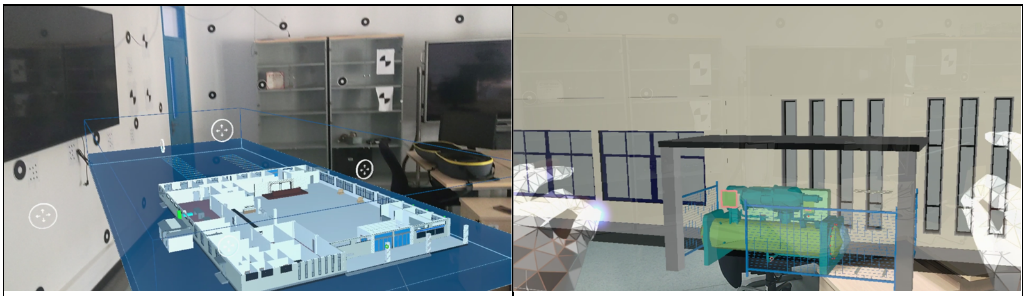


Figure 4.2 bb: Technical Process of using Mixed Reality in Gamificative Environment

(Figure 4.2.cc) shows images from HoloLens 2 for enabling interaction between people and the project model for conducting asset modelling and management. The interactive environment enables people to have a holistic understanding of items relating to the facility management process. The immersive environment enables realistic viewing, without the need for an on-site visit. HoloLens 2 has SLAM technology for locating user position, hence identifying the real-time location of the user in the virtual environment for establishing interactivity. The scene from HoloLens 2 shows that not only a bird's eye perspective can be presented in the virtual environment, but also the first-person perspective can be created.





View 3 View 4

Figure 4.2 cc: AIM Scenes from HoloLens 2

The immersive and interactive environment in HoloLens provides a holistic view of the asset system, with the relation of the building elements clearly presented through the Mixed Reality environment. The successful deployment of the proposed technical solution for the gamificative environment indicates that the proposed conceptual framework can impact the visualization process during information coordination.

Impact 3: CDE for Collaboration

Data accessibility is important during the asset management process, but the traditional method of facility management is limited in remotely accessing project data. Before the arrival of the 3D information model, facility management was based on 2D drawings and Excel sheets, stored on the hard drives of office computers. This limited access to facility information led to project delay. Furthermore, this traditional method of data management causes inefficiency; one US report indicated that 35% of time is wasted on searching for project data. This project has adopted the requirements of ISO 19650 to use the Common Data Environment (CDE) to carry the project data for facility management, which impacts the coordination of building information in terms of accessibility.

The role of CDE is not limited to storage of data, but also provides a link between information production and information management. The CDE chosen by this project is Trimble Connect, which is a platform that can provide access to stored data. This particular CDE developed is ideal for the current AEC market because it can read almost every data format and visualize them through the online platform. Therefore, all the data produced from project development can be uploaded into Trimble Connect for sharing and commenting. However, there are still limitations: people cannot directly work on the project through the platform and any modification or feedback needs to be uploaded again. Despite the limitations in the technical process, this CDE provides an environment for visualizing project data and for collaboration during the project development process.

This research has proposed a new method of facility management through the integrated Mixed Reality environment via a Common Data Environment (CDE). The role of CDE in this project is similar to visualization engines, which can provide a platform for both project team and stakeholders to establish communication and collaboration through the visualized and interactive environment. Each member of the project team can access the data via a simple application on a device across different operating systems. With this improved accessibility, the project team can acquire the required information for review and comments. All comments also show in the CDE; therefore, everyone can access the same information for efficient collaboration.

Facility Management normally includes a large number of people operating in a hierarchy with different responsibilities, ranging from management level to action level. How information from management level be efficiently delivered to action level and how information from each level can be shared with other levels depends on data accessibility. The traditional way of delivering data is not centralized, causing chaos and loss of data. In facility management, it is important that everyone has access to the same information.

The project team in this experiment uploaded the produced file from 3D information modelling software into Trimble Connect, from where these models can be shared with other team members for review and comments. Also, through Trimble Connect, the model can be accessed via the second generation of HoloLens with a Mixed Reality environment for immersive and interactive project review. In this perspective, since all the design data are centralized, no additional data share is required for evaluation and assessment. The project team can use mobile devices to access the data from a distance.

The proposed solution to access data to increase information coordination via this conceptual framework increases collaboration not only within the project team, but also with stakeholders. Improved collaboration can impact efficiency in design development, which can subsequently lead to enhanced business operation performance of building design companies. Therefore, the findings show that the CDE can increase data accessibility during information coordination, which can improve collaboration and impact the design business.

Impact 4: Coordination of the Data Exchange Process

This Asset Information Model (AIM) development project involves many processes to establish the Asset Management System (AMS). These processes include data collection, data processing, information production, integration, visualization, and management. Between each step, there is a demand for data exchange for the next step. (Figure 4.2. dd) shows the process of development along the project. All the process are linked with Exchange Information Requirement according to the criteria of ISO19650. Structured data exchange management enables the project to be developed in an organized way. There are three main data exchange steps in this project, which are: Data Collection to Information Production, Information Production to Integration, and Integration to Facility Management.

Also, (Figure 4.2. dd) shows the role of gamification in the facility management process. Since facility management is heavily dependent on the quality of 3D information models, the dynamic and interactive environment created by gamification improves the development of the BIM model. The increased communication in the modelling process enables provision of clear information requirements for ensuring the project is running on the right track. Moreover, which the sufficient information requirement instructions through improved interaction and communication, the facility management team is enabled to make timely decisions for taking certain actions.

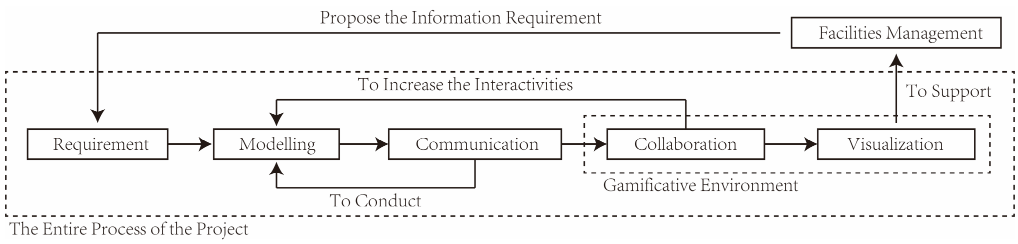


Figure 4.2 dd: Development Process of Intervention Study 3

From data collection to data process, the data need to be transferred from survey equipment to local hard drive, which requires portable disks in the correct format for reading by equipment and PC compatible with Windows, MacOS and Linux. These disk formats include FAT32, NTFS, and exFAT. The remaining step is quite similar to the previous two interventions, which is involved with the collaboration of multiple software. The version and the compatibility of the software need to be considered during the information planning of the data exchange process.

According to ISO 19650 (2018), these formats during the data exchange need to be clearly stated in the EIR, and the BEP needs to clearly address how these data will be exchanged. This project has produced a BEP with detailed plans and schedules for data exchange during the project development, according to the proposed conceptual framework through the adoption of ISO 19650 criteria. The structured data exchange followed by EIR and BEP provides clear guidance for establishing the collaborative and interactive environment for Facility Management.

During the project development, three types of data collection tools are being used, which are SLR camera, Laser Scanner, and GNSS. This project has successfully transferred the data from these three pieces of equipment to Windows-based PC for further process, and Laser Scanner data are mostly used during project development. Data exported from Laser Scanner is processed in Autodesk ReCap and exported as an RCP file for importing to Revit as reference. Once each discipline's Asset Information Model (AIM) is built in Revit, the exported RVT files are transferred to a Rendering Engine such as Lumion and Enscape3D for better visualization. For Asset Management, the project uploads the RVT file to Trimble Connect for team collaboration and Mixed Reality Integration.

Although there are limitations in the selected Common Data Environment, all the data are successfully exchanged throughout the project development. A clearly planned BEP gives instructions during each process of data development. In BEP, all the IT mobilization, scheduling and process development are required by ISO 19650, and the proposed conceptual framework adopts these criteria, hence impacting the data exchange information coordination.

Interrelationship and Thematic Analysis

The third intervention study is testing the impact of a gamificative environment based on the findings of the first and second actions. In the previous two interventions, the role of interactive and immersive technologies in building design is studied. In this last intervention, a more advanced technical approach is being added. The strength of technical adoption is being increased in a progressive way from the first to third intervention of this action research. The first intervention is preliminarily, testing the gamificative environment by using the simplest technical solution, the second intervention is adding a cloud environment to allow project participants to access the data in a simpler way through mobile devices, and the third intervention is using much more advanced technical solutions to create the immersive and interactive environment. The results from the evaluation have shown that the immersive-based interactive technologies through the combination of both software and hardware can impact Data Accuracy and Sufficiency, Data Visualization, Data Accessibility, and Data Exchangeability. The results meet with expectations from the proposition.

The project was successfully completed within one month (in September 2020). The role of gamification in facility management is similar to building design because they both require efficient information coordination. The results from this intervention study show that the gamificative environment under the technical process of Mixed Reality within the proposition impacts project development, which achieves positive outcomes. The limitation captured from this project can help future research. Through evaluation throughout the project development, the gamificative environment depends on the quality of the model detail, and the quality of model detail depends on the process of project development. Therefore, the results of this intervention show the role of LOD 350 and ISO 19650, according to their specifications and criteria.

Since the quality of the 3D information model focuses on its accuracies and sufficiency in building geometries, the modelling process focuses on the graphical representation of the building components based on LOD 350 specifications. Different software and tools are used in this approach; graphical software such as SketchUp is used for establishing high detail graphical information, which is then integrated into Autodesk Revit for combining both graphical and non-graphical data. This process involves data exchange, following the criteria of ISO 19650. Hence, the project shows that there is an inseparable relation between LOD 350, ISO 19650, and the gamificative environment.

The gamificative environment is aimed at establishing the interaction between people and AIM through a virtual environment for obtaining the continuous feedback during the assessment and reviewing process, hence improving collaboration during project development. Also, the gamificative environment aims to provide sufficient interaction and collaboration to increase project efficiencies. The project has adopted this scheme to enable people to view the project data collaboratively and interactively through the CDE-based gamificative environment. With successful deployment in HoloLens, this research has found that the development process is most impacted by using the proposed solution regarding factors identified in information coordination.

The results show that despite the existence of technology, its implementation depends on process and workflow for achieving the gamificative environment, visualized in an immersive and interactive way. Therefore, it can be generalized that the direction of the proposition is correct, and the coordination of project information is impacted. According to the evaluation, the quality of the 3D information model impacts the visualization of the Mixed Reality environment, as the HoloLens projecting the virtual model into the hologram is based on the produced graphical data; The Mixed Reality environment can improve interaction between people and the virtual environment for increasing collaboration; the process and development of the gamificative deployment relies heavily on clear specifications and criteria as strategical references. The identified impact from third intervention study is shown in (Table 4.2.d).

Table 4.2 d: Identified Impacts from Intervention Study 3

	LOD 350	ISO 19650	Gamification
Data Accuracy	√		
Data Sufficiency	√		
Data Visibility			√
Data Accessibility		√	
Data Exchangeability		√	

Although this intervention study has no relation with commercial business, from the way it operates, it provides a paradigm for the later commercial-based project. Collaboration, considered as one of the most important factors during design production, is impacted through adoption of the proposition by using the MR-based gamificative environment. The key impact on collaboration is from the adopted CDE based on the criteria of ISO 19650, and the CDE being used in this project is considered as the most appropriate as it has most of the required functions to connect multiple devices through an online-based cloud drive. With the accessibility and exchangeability of data through CDE (Figure 4.2.ee), the deployment of Mixed Reality is conveniently accessed and, despite the extra cost of the CDE software, it saves a great deal of time and effort by not having to manually deploy the model to HoloLens.

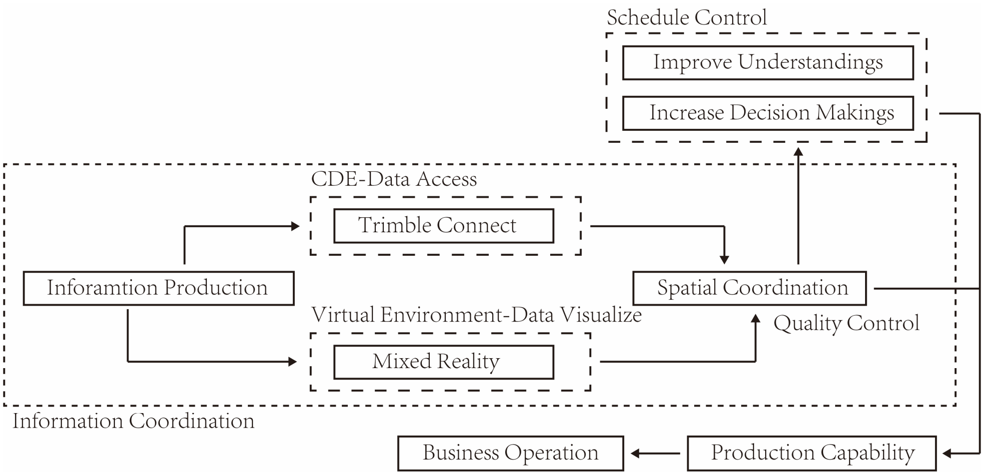


Figure 4.2 ee: Impact on Business Operation (Intervention Study 3)

The building design business operation is depending on quality and schedule control. With immersive and interactive access to building design data, the project team can comprehensively understand the design information via the virtual environment. The increased understanding enables the project team to have the decision-making much faster on whether to sign-off the project or mediate further. Hence, with the improved efficiencies in evaluation and assessment, the schedule control capability is increased, then business operation is impacted due to increased speed in the design cycle.

The quality of the immersive environment in HoloLens is depends on the quality of the 3D information model, and the detail level of the 3D information model determines its spatial and functional quality. It is found that LOD 350 can effectively guide information production for increasing construction detail for the coordination of building elements in the virtual environment. Therefore, business operation performance can be impacted by LOD 350.

Summary of Intervention 3

This research adopted a wearable headset-based interactive and immersive solution to establish the gamificative environment. This type of technology is cutting-edge, and uses an advanced positioning system to generate holograms to visualize the project design. Compared with the technologies in first two interventions, the wearable headset allows end-users to enter the real-scale virtual environment and feel the spatial and functional coordination, which could realistically reflect the design content.

Through the third intervention, the results from the evaluation support the role of immersive technologies in building design. The interactive and immersive technologies consist of both hardware and software, which require significant development of data exchange and integration. Therefore, all the factors in the coordination of information are impacted by the proposed solution in this action research. Although not directly associated with business, it links many aspects of the actual building design business operation, such as collaboration, communication, and decision-making, which can provide a reference for building design companies in their business operation.

4.3 Findings and Discussions

The action research goes through three intervention studies by using different technical approaches to identify the impact from the gamificative environment on building design information coordination. The impacts are focused on three parts, which are people, process, and technologies. Findings show that LOD 350 impacts data accuracy and data sufficiency, ISO 19650 impacts data accessibility and data exchangeability, and Gamification impacts data visibility. The finding features of ISO 19650 are clear requirement, clear procedure, and accurate interrelation; the finding features of LOD 350 are actual precision, actual position, and accurate interrelation; the finding features of gamification are comprehensiveness, immersive, and interactive (See Table 4.3.a).

Table 4.3 a: Impacts from LOD 350, ISO19650, and Gamification

	Visibility	Accessibility	Accuracy	Sufficiency	Exchangeability
LOD 350					
Actual Precision	√		√	√	
Actual Position	√		√	√	
Accurate Interrelation	√		√	√	
ISO 19650					
Clear Requirement		√		√	√
Clear Procedure		√		√	√
Clear Responsibility		√		√	√
Gamification					
Comprehensiveness	√	√		√	
Immersive	√	√		√	
Interactive	√	√		√	

Experiments in three intervention studies show the impacts from different interactive and immersive technologies; limitations are also identified, according to the approach, of using different technical approaches (see Table 4.3.b). For the PC-based technology used in the first intervention, although it is interactive, it is not portable and is relying on hardware; for panorama web-based technology used in the second intervention, although it is portable to access the project data, the visualization is not comprehensively enough; for wearable headset-based technology used in the third intervention, although comprehensive, immersive, and interactive, it is still not sophisticated enough to carry the volume of data due to limitations in state-of-the-art technical solutions and it is too expensive to purchase the equipment.

Table 4.3 b: Impacts and Limitations from Different Technologies

	Technology	Impacts	Limitations
Intervention 1	PC-based	Allow interactive view of project data	Not portable, rely on hardware
Intervention 2	Web Panorama-based	Allow portable and convenient sharing/access to data	Not comprehensive enough
Intervention 3	Wearable Headset-based	Allow interaction with model, convenient share/access to data, and immersive view of design	Technology not very sophisticated and is not affordable to most people

Three intervention studies found that the gamificative environment has three impacts and dependencies on building design management, which are, comprehensively visualize the design content (depends on a high quality 3D information model for data accuracy and data sufficiency), increase interaction between people and virtual environment (depends on technical support from relevant technologies), and improve collaboration within the project team (depends on an effective Common Data Environment (CDE)). LOD 350 can guide the development of information production to a suitable level, the gamificative environment can provide interaction between people and virtual environment, and ISO 19650 can manage information development. Findings from intervention study links features of LOD 350 for impacting data accuracy and sufficiency, links ISO 19650 for impacting data accessibility and exchangeability, and links ggamification for impacting data visibility to argue the feasibilities of adopting gamificative environment on building design information coordination.

Therefore, the findings from the three interventions are: the establishment of such a dynamic environment requires high-level coordination of different technologies; the visualization of the gamificative environment depends on the detail level of the 3D information model; communication through the gamificative environment requires the integration of different processes. Hence, importance of People, Process, and Technology is highlighted, which is the original BIM paradigm during project development. With the findings from both literature review and action research, this research argues that technology relies on people and process, because without a clear strategy, technology cannot be implemented in an effective way. (Table 4.3.c) demonstrates the contribution of the gamificative environment and premise of implementation.

Table 4.3 c: Impact of the Gamificative Environment

	Contributions	Premise
Point a.	The proposed gamificative environment allows design data to be presented in a comprehensive way	A high quality of 3D information model that covers accurate and sufficient detail
Point b.	The proposed gamificative environment allows people to interact with the design data	Technical support from relevant technologies
Point c.	The proposed gamificative environment allows people to collaborate	An efficient Common Data Environment

From the findings of the analysis and evaluation in three interventions, this research has identified how project performance is linked to the gamificative environment (Figure 4.3.a). Based on the three experiments, the gamificative environment is established from a 3D information model. By using relevant technical solutions, an immersive environment is created for interaction between people and project design. With the increased interactivity, collaboration is improved, hence enhancing project performance. Three elements are involved during the intervention studies in action research: technical procedure, technical solutions, and implementation of technology.

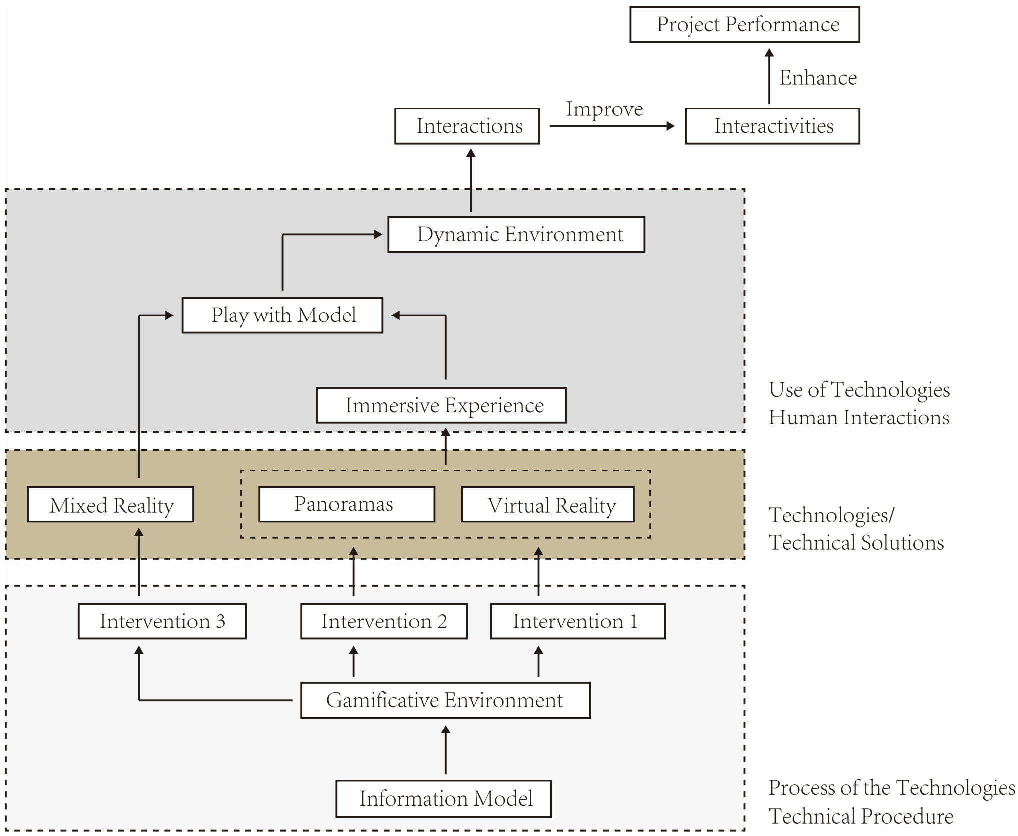


Figure 4.3 a: Gamificative Environment to Project Performance

Therefore, the findings from this research are that innovations of advanced technology can enhance project performance, but efficient technology adoption requires the coordination of people and process. The findings show that if people know how to follow the required procedures, then technologies can successfully impact design information coordination.

(Figure 4.3.b) highlights the position of people, process, and technologies during BIM implementation, the conversion of the information model into a gamificative environment is categorized as process, each gamificative environment is categorized as technology, and the use of a model is categorized as people. The diagrams illustrate the relation between these three interventions, and strengthen those technologies relying on support from the process. Also, technology can increase interactivity only through efficient use by people.

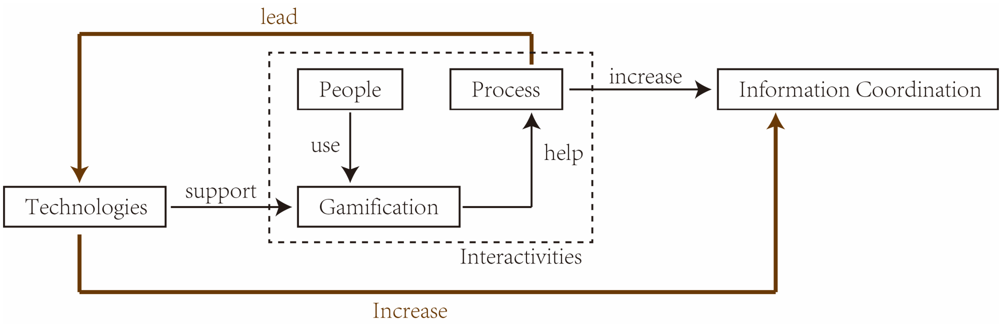


Figure 4.3 b: Interrelation between People, Process, and Technology

(Figure 4.3.c) shows the relation between gamification and technology. To establish a gamificative environment for conducting immersive and interactive visualization requires technological support. The impact of visualization to design evaluation is being categorized mainly into two parts, which are functional coordination and spatial coordination. Visualization offers an environment for spatial and functional coordination for conducting design evaluation and assessment, while the visualization itself is depending on the quality of 3D information model. Therefore, it shows the strong relation between LOD 350 and the gamificative environment, which means, features of LOD 350 can impact the spatial coordination through the gamificative environment. The actual graphical information can improve the realistic of the virtual environment for improving the assessment process. (Figure 4.3.c) shows the importance of methods and procedures, which determines that the implementation of technology requires the integration of people and process.

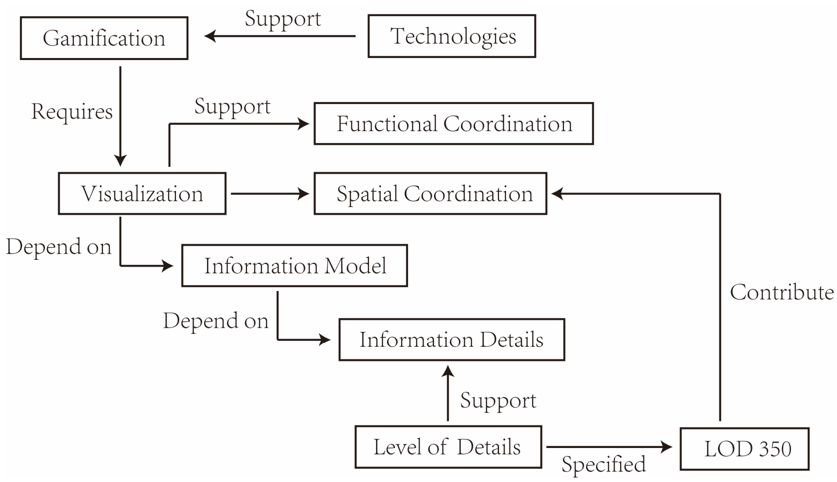


Figure 4.3 c: Interrelations in Gamification

The limitation of this action research is regarding the sample size; since this research has carried out three experiments by using three different technical approaches to establish a gamificative environment, there are more ways to have the same approach. The evaluation focuses on identifying the impact of each of the technical solutions on each factor of the information coordination. Since the analysis and evaluation are as self-reflection, this creates a limitation. From the technical aspect, the limitation identified by this research is that, to develop a full gamificative environment, excessive programming work and a User Interface (UI) is required, which is beyond the capability of the research team. Therefore, the established three gamificative environments are the prototypes for experimental purposes. Moreover, due to the current technical limitations and insufficiencies in the Common Data Environment (CDE), there is no available CDE to entirely process the data from production to evaluation.

Table 4.3 d: Findings of Impacts from Proposition

	Communication	Collaboration	Details
ISO 19650	Medium	High	Low
LOD 350	Low	Medium	High
Gamification	High	Medium	Low

With the identified relations listed in (Table 4.3.d), this research has found that

ISO 19650 is most appropriate for collaboration purposes during information coordination because it provides all the required processes and details for guiding coordination by integrating people, process, and technologies. LOD 350 is most suitable as guidance for detail development because its specification is most appropriate for developing sufficient details for building information coordination, and gamification is most suitable for the communication aspect because the immersive and interactive visualization environment enables improvement of people's understanding and increasing decision making.

ISO 19650 can help building design to properly manage its information, LOD 350 can help building design to develop a 3D information model to an appropriate depth, and Gamification can help to increase interactivities for decision making. Together, these three solutions can be integrated to impact collaboration, communication, and design development. Three key aspects of information coordination which have been identified are interaction, integration, and management. LOD 350 can be used during the integration process, ISO 19650 can be used during the management process, and Gamification can be used during the interaction process. Hence, this research proposes a new framework for information coordination in building design.

To sum up (Figure 4.3.d), this research by conducting three experiments help to design and develop a conceptual framework can impact certain factors in project information coordination. The evaluation results from the three interventions show that by implementing the proposed conceptual framework, information coordination can be impacted by data accessibility and exchangeability; also, visualization is impacted by features of LOD 350 and gamification from data accuracy and sufficiency.

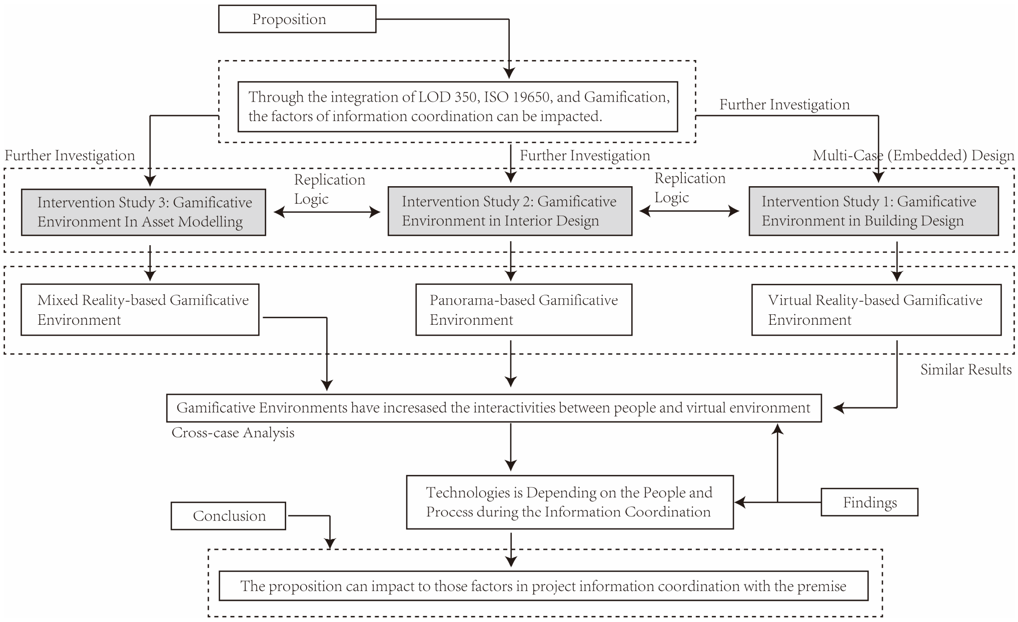


Figure 4.3 d: Summary of the Action Research

With the findings from the action research showing that building design information coordination is impacted by those features of LOD 350, ISO 19650, and gamification, the business value of the proposition is apparent. According to the literature review, business performance is associated with resources and activities to improve core capabilities. The core capabilities are categorized as core production capability with advanced production technologies. The findings from the three interventions show that the visualization and gamification strategy impact the way that the building design is developing, while both visualization and gamification require the support of relevant technologies. To sufficiently use these technologies in building design, an effective and clear SMP is required; therefore, the role of LOD 350 and ISO 19650 is to help with technology implementation to enhance the business operation as can be seen in (figure 4.3.e).

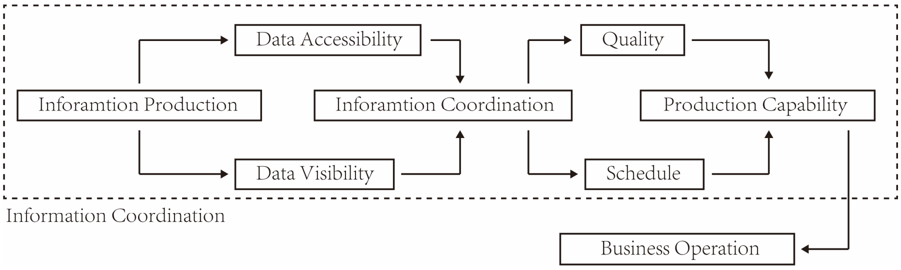


Figure 4.3 e: Impacts to Business Operation

In fact, (Figure 4.3.e) shows the interrelation between design production (Information Production) and business operation of the building design companies. Information quality and schedule are being impacted by the information coordination in terms of accessibility and visibility of project data. Therefore, the findings from the experiment through the action study show that the performance of design business operation depends on the quality of the design production.

In conclusion, the findings from this research matches the findings in preliminary research and literature review. Through the integration of LOD 350, ISO 19650, and Gamification, information coordination can be successfully increased by using gamificative environment. The experiments in three interventions are adopting the proposed conceptual framework, all factors are being tested and assessed. The evaluation results show that the impacts of the proposition meet with expectations. Therefore, this research is confident that the proposed solution can improve information coordination in building design.

4.4 Conceptual Framework

This section has discussed the primary data from the evaluation in three interventions to objectively discuss the impact of the proposed proposition on certain factors in project information coordination. According to the results, this research has identified that the quality of 3D information model, the accessibility of project information, and visualization environment for collaboration are impacted. Also, the research has identified that the gamificative environment depends on the quality of the 3D information model. Based on the 3D information model, more relevant technical solutions are required to establish the interactive environment. The use of technologies relies on people and process to efficiently conduct information management. To summarize the evaluation from each intervention, this action research has found that:

- LOD 350 can impact the graphical information development of the gamificative environment.
- People and process can impact technology adoption to create the gamificative environment.
- The gamificative environment can impact the interactivities between people and the project graphical model to conduct spatial integration.

Therefore, with the findings from the action research throughout this chapter, this research developed the proposition into a conceptual framework (Figure 4.4.a). The conceptual framework focuses on three parts: people, process, and technology. These three aspects are all linked through the Common Data Environment (CDE) for the criteria of data accessibility. As identified through three interventions, the gamificative environment requires technical support to make design data visualized in an immersive and interactive way. Also, the action research has identified that visualization is highly reliant on data accuracy and sufficiency. Therefore, the development of a 3D information model is linked with gamificative and visualization technologies. Through the adoption of technologies, people are engaged during each step of project development, according to the findings in the action study, and gamificative technology can improve immersivity of the visualization process during project development. The impacts of the conceptual framework are:

- To increase the involvement of project participants in the design process.
- To enhance the immersive experience during the building design development.
- To improve the interaction of project participants with the virtual environment.

The modelling section and the application section are linked by this conceptual framework. The modelling section focuses on the 3D information modelling process to develop a sufficiently detailed model to support implementation in the application section. The application section focuses on how to utilize the 3D information model to improve the design development process. For the IT mobilization, the appropriate technical solution has been identified according to the requirement of ISO 19650. The main technical solutions are visualization technologies and gamificative technologies. With the supporting technical process, the BIM paradigm in this conceptual framework can improve information coordination for enhancing project collaboration.

As discussed throughout the three scenarios, the operation of a building design business is impacted by the way that the collaborative environment is established. Improved data accessibilities and exchangeability enables the project team to better evaluate and visualize the data through a high-quality constructed gamificative environment; thus, the improved collaboration capabilities increase the productivity of a building design business. Thus, from this perspective, the core module of the conceptual framework needs to be focused on the collaboration platform to integrate people and process. With the improved Standards, Methods, and Procedures (SMPs), technology can have maximum value to impact information coordination, which subsequently impacts business operation.

Therefore, from a business perspective, LOD 350 and ISO 19650 are the processes that guide people during information coordination development. The value of the 3D information model is due to its nature, but the traditional method cannot reflect its value because it cannot be efficiently used in building design development. Through integrating resources and activities during the business operation, the 3D information model can be better utilized. The two loops (Figure 4.4.a) are linked by AEC technologies. Although these technologies can impact building design development, follow up with clear strategies is required for each step. From this aspect, for impacting the building design business, people, process, and technologies are considered as inseparable by this research.

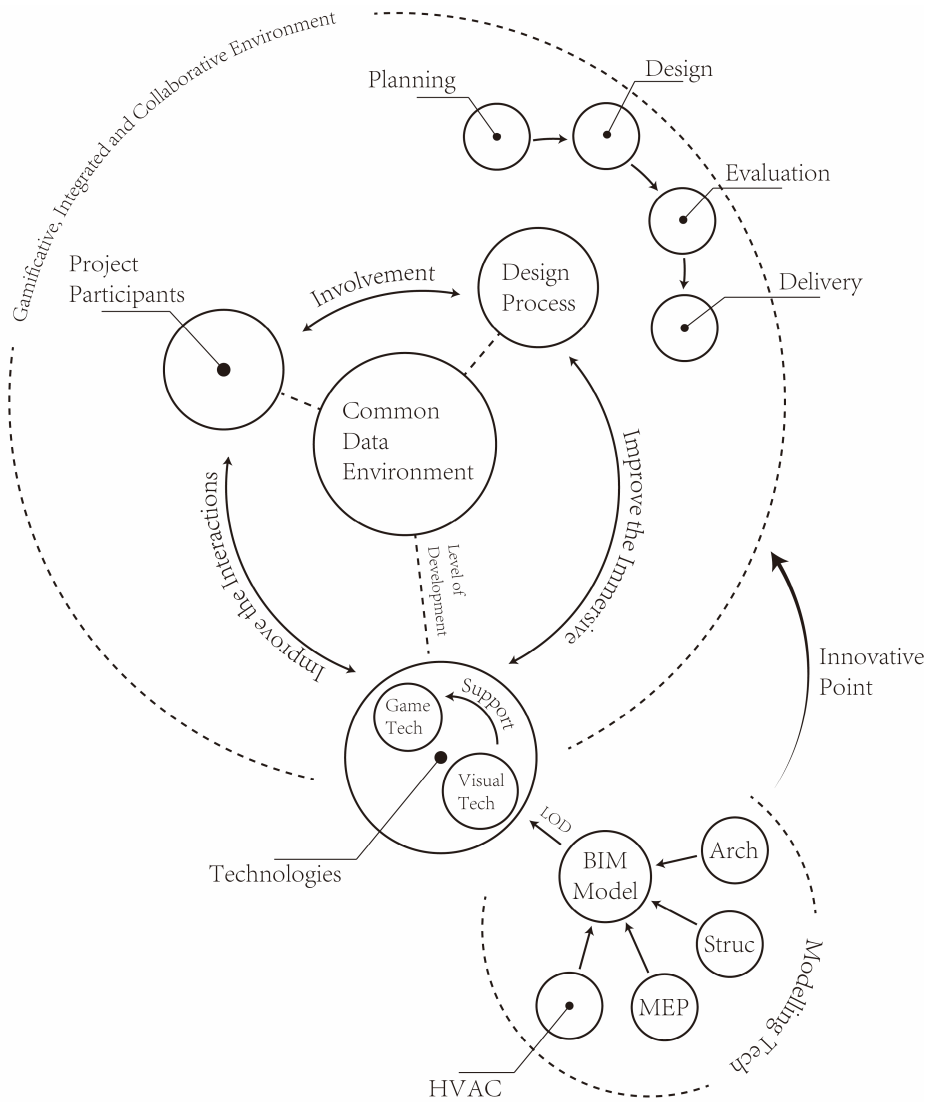


Figure 4.4 a: Amended Conceptual Framework

This conceptual framework is amended based on the proposition (1st version conceptual framework), see Chapter 2, Section 2.6, (**pp.179**). The research developed conceptual framework based on the findings from literature review and action research, which further place the position of ISO 19650, LOD 350, and Gamification along with people, process, and technology. The 1st version has proposed the interrelation between different elements to address the information coordination, and the amended version precisely placed their positions. Hence, the innovative point of this conceptual framework is that it has provided a solution to implement 3D information model (BIM Model) into the building project information coordination process.

This research names this conceptual framework the Gamificative, Integrated, and Collaborative Environment (GICE). Beyond improving information coordination, the key role of the conceptual framework is to improve the collaboration capabilities within project teams and with stakeholders during the building project. The business performance of building design companies can be enhanced through increased collaboration. This amended version of the conceptual framework is still based on the findings of this research, while more comprehensive opinions and feedback need to be collected from AEC professionals. Therefore, Chapter 5 discusses the collected primary qualitative and quantitative data from the different AEC professionals regarding their attitude toward the proposed solution of this research.

4.5 Chapter Summary

The action research has tested different interactive and immersive technologies to establish visualized gamificative environments. The results show that different technologies are having the same impacts to improve people's understandings in project design. The action research uses three interventions to study the feasibilities of using gamificative environment in building projects, and the findings indicates the importance of integrating people, process, and technologies with appropriate standards, methods, and procedures in project information coordination.

The proposed conceptual framework is the summary of the findings from action research, the conceptual framework is proposing a suitable solution to fill the gap in building design information coordination for enhancing design business operation. The main problem in building design business is low productivities caused by poor project understandings, therefore, the proposed conceptual framework can provide a new vision for building design companies to better allocate resources to improve design team's productivities. To further measure the feasibilities of this conceptual framework, Chapter 5 discusses the primary data collected from AEC professionals to make the validation.

Chapter 5 Information Coordination Impact on Building Design Business Operation

5.1 Review from Previous Findings

Chapter 2 of this research has explored potential solutions regarding how information coordination in AEC projects can be increased, how the building design business can be enhanced, how building design management needs to happen, and how technology can be involved to improve project performance. Based on existing theories, solutions, and specifications, this research has integrated different solutions and approaches to formulate a conceptual framework by using the scheme of interactive and immersive technologies during the data visualization process for enhancing understanding. The findings from the literature and systematic review have shown that gamificative technologies can help building design development to increase information coordination and enhance design productivity for business operation. With the findings, this research has tested the conceptual framework by designing the experiment through three case studies, using different gamificative technologies to create the gamificative environment for information coordination and participant observation to ascertain whether different gamificative technologies have the same impacts.

Chapter 4 conducted the experiments in three interventions by using different technical approaches to make a gamificative environment in three different types of projects. Through structured observation, this research has identified that the preliminarily proposed conceptual framework impacts each factor in project information coordination from data accuracy and sufficiency, and data accessibility and exchangeability, which enables project teams to collaborate in an immersive and interactive way through comprehensive visualization. The results from participant observation have shown that all different gamificative technologies have the same impact on different types of building project, which indicates that the gamificative environment can help building design to increase information coordination for improving the quality of the design. Therefore, with the findings and limitations from the case studies, this research has amended and developed the conceptual framework from the literature review; the conceptual framework at this stage is structured into three sections: people, process, and technology, because the research has identified that the adoption of technology relies on people following the correct SMPs.

The gamificative environment can create an immersive and dynamic environment for collaboration, thus the project participants can enhance their understanding of the design. The proposed features from the conceptual framework impact information coordination factors, which enables increased efficiency in project development. As identified from the literature review, business operation performance is related to core capabilities from the findings in the Business Model Canvas. Core capabilities involve core production capabilities, which highlight the importance of production quality and stability. Improved information coordination impacts collaboration during design production, and the quality of design production is directly linked with capability in collaboration. Therefore, the design quality impacts information coordination, which can subsequently enhance companies' business operation. In this chapter, the amended conceptual framework is developed to show how business operation is impacted by information coordination.

The aim of this research is to discover how information coordination can be improved during building project development for enhancing building design business operation. The findings from the secondary data in the literature review and primary data in the intervention show that through the adoption of a gamificative environment through the integration of suitable SMPs, the information coordination of building design development is impacted. The findings are summarized in the proposed conceptual framework, which is designed for building design companies to have a reference during project development. Although there is sufficient evidence to support the impact of the proposed solution on information coordination through participant observation, it needs to be evaluated by AEC professionals for more objective perspectives. In this chapter, the research analyses the collected primary data from different professionals in AEC industries to discuss the impact of the proposed solution, and uses the findings to further amend the conceptual framework.

The proposed conceptual framework from the literature review and action research impacts the three core aspects, which are, information coordination, building design quality, and building design business operation. According to the findings (Figure 5.1.a), the impact of the conceptual framework is divided into resources and activities, the resources mainly being production technologies, and the activities mainly including the design process. The implementation of technology creates a gamificative environment that increases the information coordination of the building design project. Once building design information is increased, project participants can become more efficient in problem detection, design modification, and optimization. These roles of information management impact the capability of building design production, which ultimately enhances the design companies' business operation.

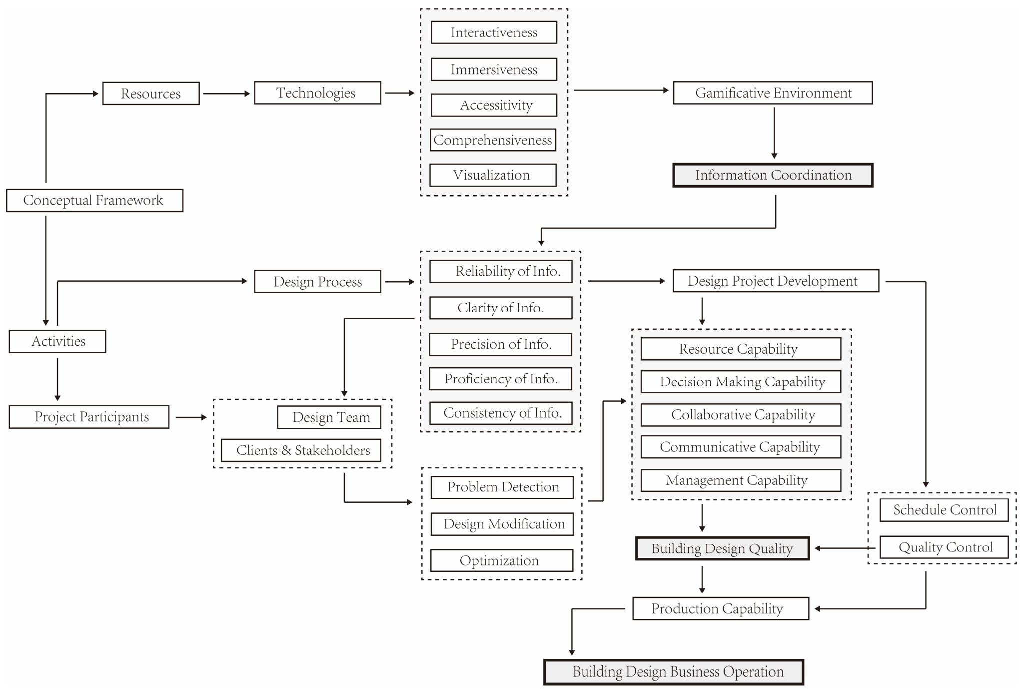


Figure 5.1 a: Impact of the proposed Conceptual Framework

The findings from the literature review and action research (Figure 5.1.a) show that data features from a gamificative environment include Interactiveness, Immersiveness, Accessibility, Comprehensiveness, and Visualization. And these features subsequently impact the development of the building design project through the increase of building design information. The development of building design relies on the following roles, as identified:

- ✧ Reliability of Information
- ✧ Clarity of Information
- ✧ Precision of Information
- ✧ Proficiency of Information
- ✧ Consistency of Information.

The roles are inherited to subsequently impact business operation capabilities of building design companies, which are:

- ✧ Resource Capability
- ✧ Decision Making Capability
- ✧ Collaborative Capability
- ✧ Communicative Capability
- ✧ Management Capability

These capabilities contribute to production capability, which can be used to enhance the building design business operation.

The rest of this chapter is structured into three parts: data collection and analysis methods, data analysis and discussion, and findings and limitations. The first part in particular deals with design of the conceptual framework in terms of research testing. At each step of the data collection and analysis, how the research sample and quantity are selected is discussed. Also, this chapter of the research explains why the focus group is selected and how the research arranges research group discussion. Moreover, the research discusses how the survey questions are designed based on the findings of the focus group discussion to measure the strength of the proposed conceptual framework and decide in which direction the gamificative environment needs to be further developed in future studies.

5.2 Analysis and Discussion of Qualitative Data

5.2.1 Data Discussion from Three Questions

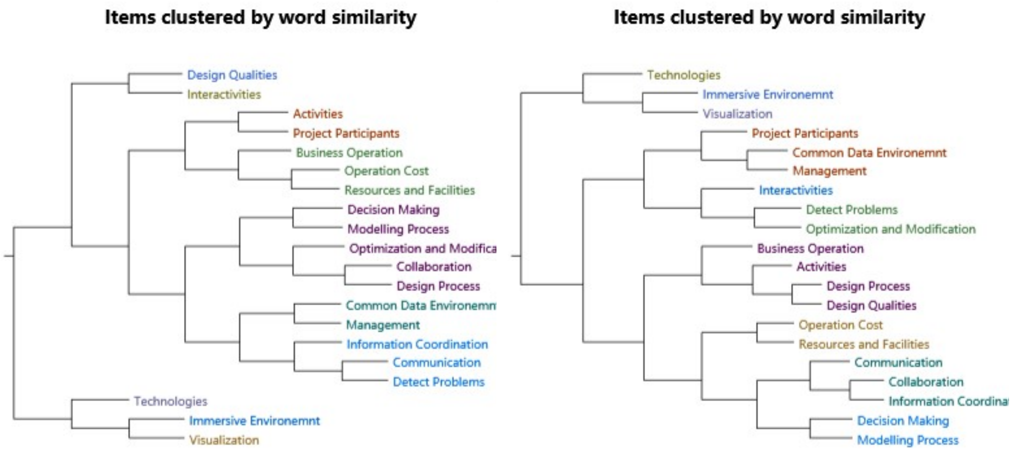
The research method of focus group regarding to data sample, data collection, and data analysis is discussed in Chapter 3, Section 3.5.3 (**pp. 228-239**). The data analysis results show that 26/26 people have answered yes on the first question, 24/26 people have answered yes on the second question, and 26/26 people have answered yes on the third question. The results prove that the proposed conceptual framework can impact information coordination, design business operation, and building design quality. On this basis, this research confirms that the conceptual framework is on the correct path.

For further developing this conceptual framework through comprehensive opinions of the AEC professionals, the research analysed the qualitative data followed by affirmative and negative answers. The research uses the collected qualitative data to investigate how the business operation of building design business can be impacted by the proposed solution from the conceptual framework.

The research places the relevant answers into each related node and analyses them based on word similarities. Three main nodes were first put into the analysis system, then NVivo outputs the clustering results by using the coefficiencies. The analysis results show that the business operation of a design company is linked to design quality and information coordination (Figure 5.2.a). This means that the way a design is operated impacts the efficiency of the information coordination, which can subsequently impact the quality of building design. This matches with the assumption of this research as regards the conceptual framework design.

Figure 5.2 a: Clustering in NVivo

Having identified the relationship between business operation, design quality, and information coordination, this research further analysed detailed coded elements. After selecting the outputs by using different coefficients, the results show two different but similar clusters. The three types of coefficients are Jaccard's, Pearson, and Sorensen's. The clustering result of Jaccard's and Sorensen's are the same, as presented in (Figure 5.2.b). Based on the output results, these nodes can be categorized as either design production or business operation. Design quality and information coordination are categorized in design production. The clustering results show the strong relation between business operation and design production, according to the focus group discussion.



Jaccard's and Sorensen's *Pearson's*

Figure 5.2 b: NVivo Clustering of Focus Group Data

The clustering results from NVivo show that the technologies mainly support the immersive and visualization environment, which shows that the BIM model needs to go through visualized and gamificative technologies for implementation in the building design development process. The results also show that the interactivities are closely linked with design development, which can identify problems, make prompt modifications, and so improve building design quality. The two results separately show that the resource allocation and activities in building design business operation are linked with the process of design development. This matches the findings from the literature review and action research that information coordination depends on resource allocation and activities managed by the design business.

From the two results from NVivo, this research has found that the Common Data Environment (CDE) will impact the management process, which enables project participants to be involved in improving the information coordination process. Hence, the relationship between the three key aspects has been clarified, according to the qualitative data analysis from the focus group discussion. Technology is used for implementation of BIM models into the design development process and, based on the gamificative environment created by relevant technologies, project participants can better be involved in the project design process through the immersive and dynamic visualized environment. CDE enables project participants to better manage the project for increasing information coordination, which can subsequently impact design quality.

5.2.2 Data Discussion from Learning Outcomes

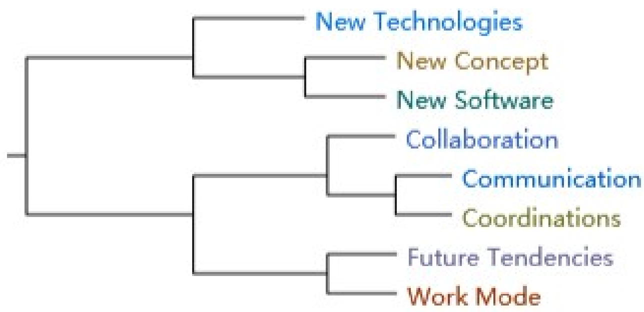


Figure 5.2 c: NVivo Clustering of Learning Outcome Data

Moreover, from the focus group, data was collected regarding participants' learning outcomes and, based on the collected data, key aspects were selected to conduct the clustering analysis in NVivo for comparing their relations. The finding results through the clustering using three coefficients are the same, as shown in (Figure 5.2.c). From the results, it can be seen that there are two major parts: technologies and collaboration. The technologies are linked with new concepts and new software, while collaboration is linked with future work mode and tendencies. Therefore, this research summarizes that collaboration depends on the support of technologies, which subsequently impact the future work mode.

Table 5.2 a: Impacts of Gamificative Environment on Business Operation

Solution	Features/Roles/ Capabilities	Impacts	Factors
Gamificative Environment	Interactiveness	Information Coordination	Data Access
	Immersiveness		Data Visualize
	Accessibility		Data Exchange
	Comprehensiveness		Data Accurate
	Visualization		Data Sufficient
Building Design Management	Reliability	Building Design Quality	Building Code
	Clarity		Clients Requirement
	Precision		Spatial/Functional (Reasonability)
	Proficiency		
	Consistency		
Production Capability	Resource	Business Operation	Quality Control
	Collaboration		Schedule Control
	Communication		
	Decision Making		
	Management		

(Table 5.2.a) shows the interrelation between each element, according to the findings from the literature review and case studies, for enhancing the business operation of building design companies, which are: Gamificative Environment, Building Design Management, and Production Capabilities. These three categories developed in a progressive, gamificative environment impacting building design management, and building design management impacts production capability. As illustrated in (Table 5.2.a), features of the gamificative environment impact information coordination, features of building design management within the gamificative environment impact building design quality, and production capability within the gamificative environment impacts business operation. Factors of information coordination, building design quality, and business operation are listed in (Table 5.2.a).

With the findings from the qualitative data analysis, this research has further designed a survey to measure the strength of each feature and capability, for showing strength of impact of the proposed conceptual framework. Section 5.3 presents the collected quantitative data from the survey and links the findings from the literature review and action research to argue how and why the gamificative environment can substantially impact information coordination, building design quality, and business operation.

5.3 Analysis and Discussion of Quantitative Data

The analysis of the data from the survey mostly focuses on the Mean and Standard Deviation (SD) because the Mean reflects the general strength of the data situation and the SD reflects the stability of the collected data. If the value of SD is low, the data is relatively concentrated in a certain value; therefore, the SD can be used to measure the stability of people's opinion regarding the features and capabilities within the gamificative environment in building design development.

For the reliability and validity of the collected data from the survey, the research uses Cronbach's Alpha to measure reliability and KMO (Kaiser-Meyer-Olkin) to test validity of the data. As commonly accepted in academia, if Cronbach's Alpha is above 0.8, the collected data has very good reliability. For the KMO test, if the result is above 0.6, then the data is acceptable for conducting further analysis.

The survey has 20 questions in total, classified as: measurement of impact on information coordination, measurement of impact on design quality, and measurement of impact on business operation. Hence, due to three different approaches, the test for reliability and validity needs to be separated. Questions

1.1 to Question 1.5 belong to information coordination, Questions 2.1 to Question 2.5 belong to design quality, and Questions 3.1 to Question 3.10 belong to business operation. The following (Table 5.3.a to Table 5.3.f) show the measurement test results:

➢ <u>Measuring Impact on Building Design Information Coordination</u>

Reliability Statistics	
Cronbach's Alpha	N of Items
0.828	5

Table 5.3. a

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.784
Bartlett's Test of Sphericity	Approx. Chi-Square	141.864
	df	10
	Sig.	0.000

Table 5.3. b

This research uses SPSS to calculate reliability and validity by adopting Cronbach's Alpha and KMO test, and the results show that the Cronbach's Alpha of the collected data is 0.828 with 5 survey questions for the measurement of information coordination using a gamificative environment (Table 5.3.a). The result from SPSS shows that the KMO measurement of the collected data is 0.784 (Table 5.3.b). Both results meet the acceptance criteria; therefore, the reliability and the validity of the data is acceptable for further analysis.

➢ <u>Measuring Impact on Building Design Quality</u>

Reliability Statistics	
Cronbach's Alpha	N of Items
0.929	5

Table 5.3. c

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.860
Bartlett's Test of Sphericity	Approx. Chi-Square	259.491
	df	10
	Sig.	0.000

Table 5.3. d

The results show the Cronbach's Alpha of the collected data is 0.929 with 5 survey questions for the measurement of building design quality using a gamificative environment (Table 5.3.c). The result from SPSS shows that the KMO measurement of the collected data is 0.860 (Table 5.3.d). Both results meet the acceptance criteria; therefore, the reliability and validity of the data is acceptable for further analysis.

- <u>Measuring Impact on Building Design Business Operation</u>

Reliability Statistics	
Cronbach's Alpha	N of Items
0.974	10

Table 5.3. e

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.931
Bartlett's Test of Sphericity	Approx. Chi-Square	946.266
	df	10
	Sig.	0.000

Table 5.3. f

The results show the Cronbach's Alpha of the collected data is 0.929 with 10 survey questions for the measurement of the building design quality using a gamificative environment (Table 5.3.e). The result from SPSS shows that the KMO measurement of the collected data is 0.931 (Table 5.3.f). Both results meet the acceptance criteria; therefore, the reliability and the validity of the data is acceptable for further analysis.

All results from the three groups of survey measurements have good reliability and validity for further analysis. Section 5.3.1 to Section 5.3.3 present data analysis from the survey.

5.3.1 Strength of Gamificative Environment Features

➢ Impact of (Data) Immersiveness

The measurement of (Data) Immersiveness from the survey shows that with the quantity of sample (N=67), the mean is 9.03 and the Standard Deviation (SD) is 1.267. (Figure 5.3.1.a) shows that most frequencies are concentrated around 9 and 10. The lowest mark is 5 and the highest mark is 10. (Table 5.3.1.a) shows the major statistics of the survey data; with 98% of the confidential level, the bound of the confidential interval is between 8.66 and 9.04, and Skewness -1.394.

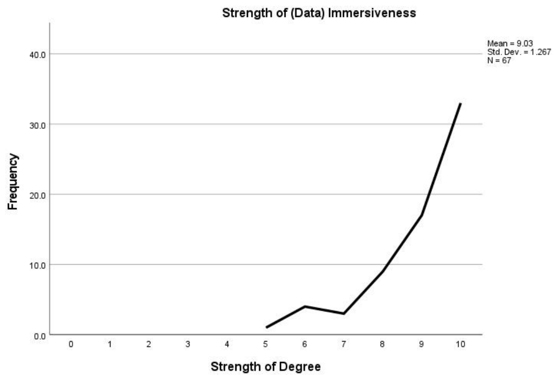


Figure 5.3.1. a

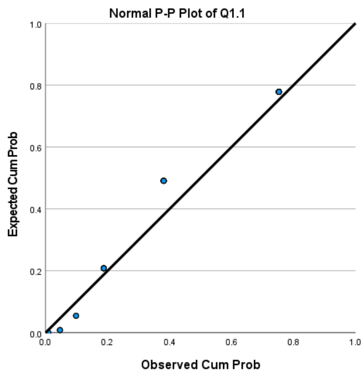


Figure 5.3.1. b

This research uses P-P Plot to show the interrelation between the actual data distribution and the normal distribution; (Figure 5.3.1.b) shows the results are relatively aligned through the diagonal curve. This result indicates that the survey answers meet the statistical criteria for validation acceptance. Hence, the strength of (Data) Immersiveness has been accepted.

Table 5.3.1. a

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q1.1	Mean		9.03	0.155
	98% Confidence Interval for Mean	Lower Bound	8.66	
		Upper Bound	9.40	
	5% Trimmed Mean		9.16	
	Median		9.00	
	Variance		1.605	
	Std. Deviation		1.267	
	Minimum		5	
	Maximum		10	
	Range		5	
	Interquartile Range		2	
	Skewness		-1.394	0.293
	Kurtosis		1.310	0.578

As statistically validated, the impact of the (Data) Immersiveness feature of the gamificative environment on information coordination in building design development is strong, since its Mean (9.03) is far higher than the Defined Value (6).

The measurement of (Data) Immersiveness of the gamificative environment through the survey shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing project participants to experience the building design in a more direct way. The situated cognition studies (Marineau et al., 2018; Petracca. 2017; Fields, 2021; Kroesbergen et al., 2019) show that realistic environment can increase people's understandings toward certain objects and improve people's performance toward certain tasks.
b) Allowing project participants to understand the design content in a more holistic way. The literature review findings (Dove et al., 2018; Holly et al., 2021; Zaker & Coloma, 2018; Hugo et al., 2022) show that immersive environment can enhance people's understandings in building design

development, which can subsequently impact on project information coordination.

Findings from the action research show that the implementation of different gamificative technologies has the same impact on establishing an immersive environment as on improving the coordination of building design information. Therefore, all the evidence and data indicate the importance of Data Immersiveness.

- <u>Impact of (Data) Interactiveness</u>

The measurement of (Data) Immersiveness from the survey shows that with the quantity of sample (N=67), the mean is 8.64 and the Standard Deviation (SD) is 1.905. (Figure 5.3.1.c) shows that most frequencies are concentrated in 8 and 10. The lowest mark is 0 and the highest is 10. (Table 5.3.1.b) lists the major statistics of the survey data, showing that with 98% of the confidential level, the bound of the confidential interval is between 8.09 and 9.20, and the Skewness is -2.219.

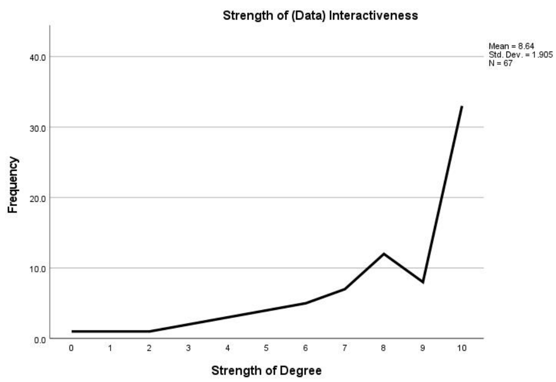


Figure 5.3.1. c

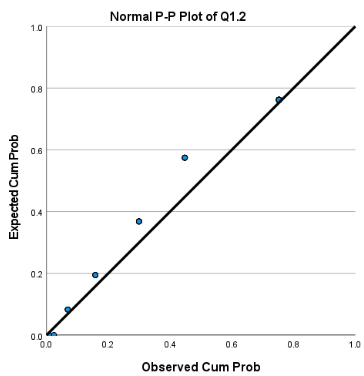


Figure 5.3.1. d

The P-P Plot (Figure 5.3.1.d) shows the interrelation between the actual data distribution and the normal distribution, and the results are relatively aligned through the diagonal curve. The results indicate that the survey answers meet with the statistical criteria for validation acceptance. Hence, the strength of the (Data) Interactiveness is accepted.

Table 5.3.1. b

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q1.2	Mean		8.64	0.233
	98% Confidence Interval for Mean	Lower Bound	8.09	
		Upper Bound	9.20	
	5% Trimmed Mean		8.88	
	Median		9.00	
	Variance		3.627	
	Std. Deviation		1.905	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.219	0.293
	Kurtosis		6.862	0.578

In this part of the survey data collection, it is significant that some people disagree that this feature can impact building design information coordination. This will be further discussed later, but most people strongly agree with the proposed statement. Therefore, as statistically validated, the impact of the (Data) Interactiveness feature of the gamificative environment on information coordination in building design development is strong, since its Mean (8.64) is much higher than the Defined Value (6).

The measurement of (Data) Interactiveness of the gamificative environment through the survey shows the strength of this feature, which matches with the findings from the literature review as regards:

a) Allowing project participants to better interoperate with the design data. According to relevant literature reviews, (Cheng et al., 2017; Zou et al., 2018; Pratama & Dossick, 2019), increased interaction between people and project design would allow people to improve understandings.

b) Allowing project participants better control over the design data. The findings from the literature review (Deterding, 2019; Alavi et al., 2019; Lin et al., 2018; Wang, 2022) show that people can better manipulate the progress of project development under the interactive environment.

Findings from the action research show that Interactiveness through the gamificative environment allows more contact with project data, in a more intuitive way, and more effective comments and feedback. Therefore, all the evidence proves the validity of this feature.

➢ Impact of (Data) Accessibility

The measurement of (Data) Immersiveness from the survey shows that with the quantity of sample (N=67), the mean is 8.48 and the Standard Deviation (SD) is 2.163. (Figure 5.3.1.e) shows that most frequencies are concentrated in 8, 9, and 10. The lowest mark is 0 and the highest is 10. (Table 5.3.1.c) lists the major statistics of the survey data, showing with 98% confidential level, the bound of the confidential interval is between 7.85 and 9.11, and the Skewness is -2.145.

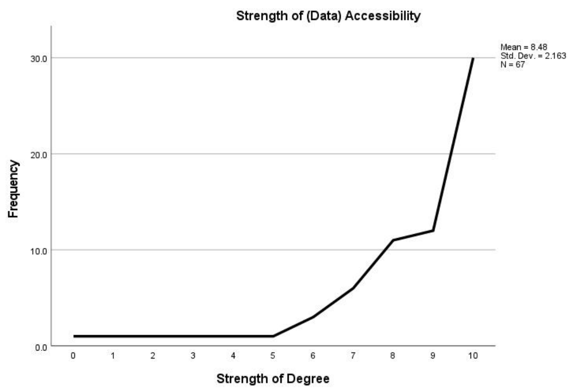


Figure 5.3.1. e

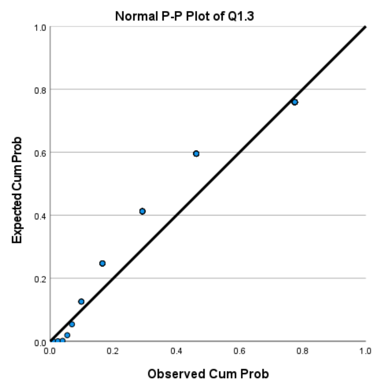


Figure 5.3.1. f

The P-P Plot (Figure 5.3.1.f) shows the interrelation between the actual data distribution and the normal distribution, and the result is relatively aligned through the diagonal curve. This result indicates that the survey answer meets the statistical criteria for validation acceptance. Hence, the strength of the (Data) Accessibility is accepted.

Table 5.3.1. c

<table>
<tr><td colspan="5">Descriptive Statistical Analysis</td></tr>
<tr><td colspan="3"></td><td>Statistic</td><td>Std. Error</td></tr>
<tr><td rowspan="14">Q1.3</td><td colspan="2">Mean</td><td>8.48</td><td>0.264</td></tr>
<tr><td rowspan="2">98% Confidence Interval for Mean</td><td>Lower Bound</td><td>7.85</td><td></td></tr>
<tr><td>Upper Bound</td><td>9.11</td><td></td></tr>
<tr><td colspan="2">5% Trimmed Mean</td><td>8.79</td><td></td></tr>
<tr><td colspan="2">Median</td><td>9.00</td><td></td></tr>
<tr><td colspan="2">Variance</td><td>4.678</td><td></td></tr>
<tr><td colspan="2">Std. Deviation</td><td>2.163</td><td></td></tr>
<tr><td colspan="2">Minimum</td><td>0</td><td></td></tr>
<tr><td colspan="2">Maximum</td><td>10</td><td></td></tr>
<tr><td colspan="2">Range</td><td>10</td><td></td></tr>
<tr><td colspan="2">Interquartile Range</td><td>2</td><td></td></tr>
<tr><td colspan="2">Skewness</td><td>-2.145</td><td>0.293</td></tr>
<tr><td colspan="2">Kurtosis</td><td>5.129</td><td>0.578</td></tr>
</table>

The survey data shows that some people disagree that this feature can impact building design information coordination, with some data showing strength of impact between 0 and 4. The reason for this will be further discussed later in this research, but most people strongly agree with the proposed statement. Therefore, as statistically validated, the impact of (Data) Accessibility feature of the gamificative environment is high, in terms of information coordination in building design development, as its Mean (8.48) is much higher than the Defined Value (6).

The measurement of (Data) Accessibility of the gamificative environment through the survey has shown the strength of this feature, which matches the findings from literature review as regards:

a) Allowing project participants to better acquire the demanded information.

Findings from the relevant literature (Borrmann et al., 2018; Park & Lee, 2017; Lee & Lee, 2021) show that the accessibilities of project data impact on the performance of teamwork.

b) Allowing project participants to better distribute the demanded information. The findings (Tayeh & Issa, 2020; Van et al., 2020; Holzer, 2016; Akponeware & Adamu, 2017; Lee & Chong, 2021) show that the timely shared project data will impact on the project performance.

Findings from the action research show the impact of the Common Data Environment (CDE) and online presenting platform, as it has proved the importance of the availability of the project data in information coordination. Therefore, all the findings point to the importance of this feature of the gamificative environment.

➢ Impact from (Data) Visualization

The measurement of (Data) Visualization from the survey shows that with the quantity of sample (N=67), the mean is 9.07 and the Standard Deviation (SD) is 1.283. (Figure 5.3.1.g) shows that most frequencies are concentrated in 9 and 10. The lowest mark is 5 and the highest is 10. (Table 5.3.1.d) lists the major statistics of the survey data, showing that with 98% of the confidential level, the bound of the confidential interval is between 8.70 and 9.45, and the Skewness is -1.386.

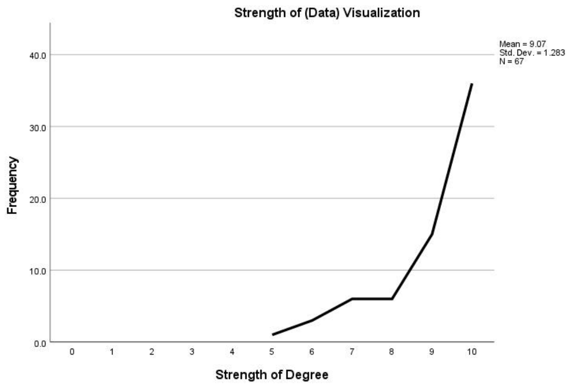


Figure 5.3.1. g

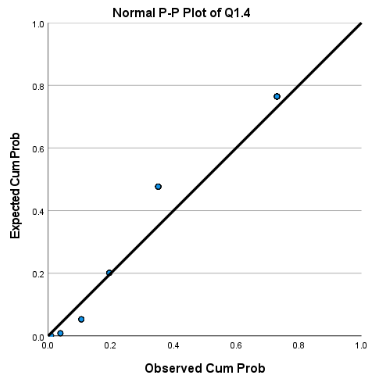


Figure 5.3.1. h

The P-P Plot (Figure 5.3.1.h) shows the interrelation between the actual data distribution and the normal distribution, and the result is relatively aligned through the diagonal curve. This result indicates that the survey answer meets the statistical criteria for validation acceptance. Hence, the strength of the (Data) Visualization is accepted.

Table 5.3.1. d

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q1.4	Mean		9.07	0.157
	98% Confidence Interval for Mean	Lower Bound	8.70	
		Upper Bound	9.45	
	5% Trimmed Mean		9.21	
	Median		10.00	
	Variance		1.646	
	Std. Deviation		1.283	
	Minimum		5	
	Maximum		10	
	Range		5	
	Interquartile Range		1	
	Skewness		-1.386	0.293
	Kurtosis		1.081	0.578

As statistically validated, the impact of the (Data) Visualization feature of the gamificative environment on the information coordination in building design development is strong, as its Mean (9.07) is much higher than the Defined Value (6).

The measurement of (Data) Visualization of the gamificative environment through the survey has shown the strength of this feature, matching the findings from literature review as regards:

a) Allowing the design team to better present the project data. Findings from the literature review (Cha et al., 2019; Knotten et al., 2017; Zhu et al., 2018; Hugo et al., 2022) show that visualized project data will impact on decision-making efficiencies.
b) Allowing the design team to better assess and evaluate the project design. The literature review (Suryawinata, 2021; Liu et al., 2017; Pikas et al., 2018) highlights the performance of project evaluation and assessment will be impacted under visualized environment.

Findings from the action research show that the gamificative environment contributes to the illustration of project data during design development for enhancing information coordination. Thus, all the results show that this feature plays an important role.

➢ <u>Impact of (Data) Comprehensiveness</u>

The measurement of (Data) Comprehensiveness from the survey shows that with the quantity of sample (N=67), the mean is 8.91 and the Standard Deviation (SD) is 1.443. (Figure 5.3.1.i) shows the most frequencies are concentrated in 9 and 10. The lowest mark is 4 and the highest is 10. (Table 5.3.1.e) lists the major statistics of the survey data, which shows that with 98% of the confidential level, the bound of the confidential interval is between 8.49 and 9.33, and the Skewness is -1.335.

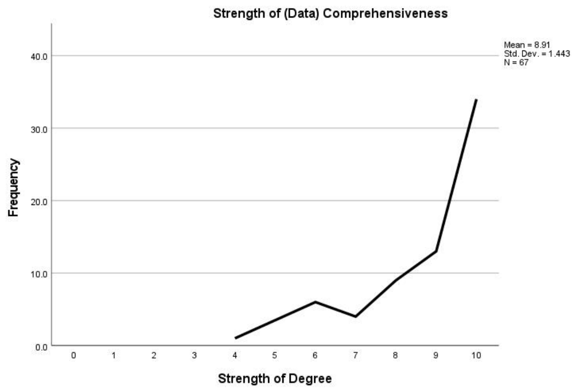


Figure 5.3.1. i

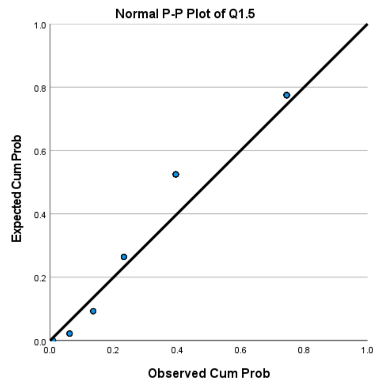


Figure 5.3.1. j

The P-P Plot (Figure 5.3.1.j) shows the interrelation between the actual data distribution and the normal distribution, with the results relatively aligned through the diagonal curve. This result indicates that the survey answers meet with the statistical criteria for the validation acceptance. Hence, the strength of the (Data) Comprehensiveness is accepted.

Table 5.3.1. e

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q1.5	Mean		8.91	0.176
	98% Confidence Interval for Mean	Lower Bound	8.49	
		Upper Bound	9.33	
	5% Trimmed Mean		9.04	
	Median		10.00	
	Variance		2.083	
	Std. Deviation		1.443	
	Minimum		4	
	Maximum		10	
	Range		6	
	Interquartile Range		2	
	Skewness		-1.335	0.293
	Kurtosis		1.140	0.578

As statistically validated, the impact of the (Data) Comprehensiveness feature of the gamificative environment on information coordination in building design development is strong, as its Mean (8.91) is much higher than the Defined Value (6).

The measurement of (Data) Comprehensiveness of the gamificative environment through the survey shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing project participants to better make decisions. Findings from the literature review (Liu et al., 2017; Mataloto et al., 2020; Abouelkhier et al., 2021; Wang et al., 2016) indicate that mutual agreement is relying on whether the data is comprehensive.
b) Allowing the design team to better make modifications. According to the literature review (Sanches et al., 2017; Shillcock & Cao, 2019b; Uusitalo et al., 2018), the quality of project development is relying on whether all the data are covered for assessment and evaluation.

Findings from the action research show the importance of comprehensiveness of project data in building design development in terms of consistency. Therefore, the results from both primary and secondary data show the significance of this feature of the gamificative environment.

Table 5.3.1. f

Information Coordination	
Immersiveness	Impact on holistic understanding of the project
Interactiveness	Impact on activities in the virtual environment
Accessibility	Impact on effective project development
Visualization	Impact on efficient assessment reviewing
Comprehensiveness	Impact on quality of project delivery

Therefore, statistical results have shown that all five features of the gamificative environment have a strong impact on information coordination in building design development (Table 5.3.1.f). The findings from the literature review regarding the impact of (Data) Immersiveness, (Data) Interactiveness, (Data) Visualization, (Data) Accessibility, and (Data) Comprehensiveness match the findings from quantitative data collected from the survey. The feature of accessibility is the foundation of information coordination, which provides an accessible platform for immersive and comprehensive visualization. Data Interactiveness is a key aspect of the gamificative environment.

Table 5.3.1. g

	Immersive	Interactive	Visualize	Accessible	Comprehensive
Mean	9.03	8.64	8.48	9.07	8.91
SD	1.267	1.905	2.163	1.283	1.443

The statistics resulting from the survey show that all features of the gamificative environment have a high mean, all close to 9.00 (Table 5.3.1.g). For the Standard Deviation (SD), the table shows that (Data) Immersiveness and (Data) Accessibility is close to 1.000, while (Data) Interactiveness and (Data) Visualization is close to 2.000. However, these deviations are not too high, which means the data collected from the survey is very stable. Therefore, it can be concluded that the strength of these features is high and relatively stable.

5.3.2 Strength of Information Management Characters

In this part of the data analysis, the research uses the same approach as section 5.4.1 to statistically measure the strength of information management within the gamificative environment.

- <u>Information Reliability on Building Design Quality</u>

The measurement of Information Reliability from the survey shows that with the quantity of sample (N=67), the Mean is calculated as 9.00 and Standard Deviation (SD) as 1.403. As the detailed statistics in (Table 5.4.2.a) show, the score ranges from 4 to 10, with most frequencies concentrated between 8 and 10 (Figure 5.4.2.a). The research has selected a 98% confidential level due to the findings from the focus group on the conceptual framework. Therefore, the confidence interval from the statistics shows the upper bound as 9.41 and the lower bound as 8.59. The skewness of the normal distribution is -1.525 with kurtosis of 2.085.

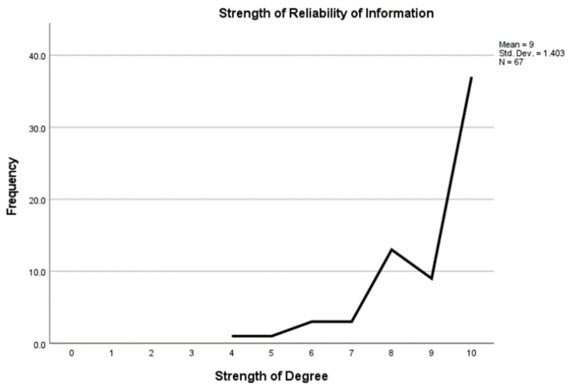


Figure 5.3.2. a

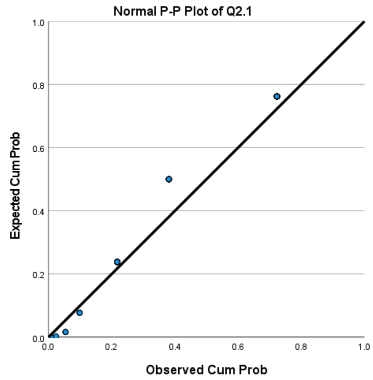


Figure 5.3.2. b

The P-P Plot shows that the normal distribution is closely aligned with the statistics, with points near the diagonal curve (See Figure 5.3.2.b). Therefore, the P-P Plot shows that the statistics are valid for acceptance. Hence, the strength of the (Information) Reliability in the gamificative environment is accepted.

Table 5.3.2. a

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q2.1	Mean		9.00	0.171
	98% Confidence Interval for Mean	Lower Bound	8.59	
		Upper Bound	9.41	
	5% Trimmed Mean		9.16	
	Median		10.00	
	Variance		1.970	
	Std. Deviation		1.403	
	Minimum		4	
	Maximum		10	
	Range		6	
	Interquartile Range		2	
	Skewness		-1.525	0.293
	Kurtosis		2.085	0.578

According to the statistics, the findings show that the Information Reliability of information management within the gamificative environment has a strong impact on building design quality, because the Mean is (9.00), which is much higher than the expected value of (6).

The measurement of (Information) Reliability of management within the gamificative environment through the survey shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing correct data sourcing (input) of the project design. The findings from the literature review (Cooper, 2019; Boujaoudeh, 2019; Bjørn et al., 2021; Prabhakaran et al., 2021) show that the reliability of the existing information helps to avoid any potential bias and confusions.
b) Allowing correct data generation (output) of the project design. Findings from the relevant studies (Aguiar et al., 2019; Tayeh & Issa, 2020; Latini, 2021; Lundmark, 2018) show that the quality of collaboration is depending on whether the data is reliable.

Findings from action research show that the information carrier in the gamificative environment supports the project team to acquire and produce the correct information for project development. Therefore, the findings show that this feature of the gamificative environment does have a strong impact.

➢ <u>Information Clarity on Building Design Quality</u>

The measurement of Information Clarity shows that with the quantity of sample (N=67), the Mean is calculated as 9.04 with a Standard Deviation (SD) of 1.261. As the detailed statistics in (Table 5.3.2.b) show, the score ranges from 5 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.2.c). This research uses a 98% confidential level due to the findings from the focus group on the conceptual framework. Therefore, the confidential interval from the statistics shows an upper bound of 9.41 and a lower bound of 8.68. The Skewness of the normal distribution is -1.350 with Kurtosis of 1.136.

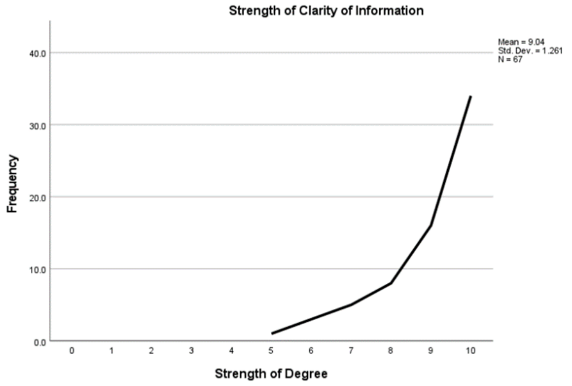


Figure 5.3.2. c

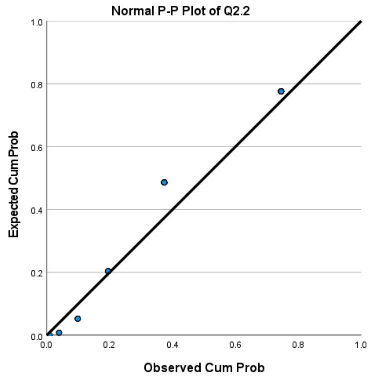


Figure 5.3.2. d

The P-P Plot shows that the normal distribution is closely aligned with the counted statistics, with points near the diagonal curve (See Figure 5.3.2.d). Therefore, the P-P Plot shows that the statistics are valid for acceptance. Hence, the strength of (Information) Clarity from the gamificative environment are accepted.

Table 5.3.2. b

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q2.2	Mean		9.04	0.154
	98% Confidence Interval for Mean	Lower Bound	8.68	
		Upper Bound	9.41	
	5% Trimmed Mean		9.18	
	Median		10.00	
	Variance		1.589	
	Std. Deviation		1.261	
	Minimum		5	
	Maximum		10	
	Range		5	
	Interquartile Range		2	
	Skewness		-1.350	0.293
	Kurtosis		1.136	0.578

According to the statistics, the findings show that the Information Clarity of information management in the gamificative environment has a strong impact on building design quality, because the Mean is (9.04), which is much higher than the expected value of (6).

The measurement of (Information) Clarity of management in the gamificative environment shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing the project team to obtain clear project requirements. According to the findings from the literature review (Lai et al., 2019; Pikas et al., 2020; Cardellicchio & Tombesi, 2021; Montali et al., 2019), poor understandings of project requirements will lead to chaos in design production.
b) Allowing the project team to produce clear design information. Findings from the literature (Park et al., 2017; Gana et al., 2018; Boujaoudeh, 2019) show that satisfying all project requirement can positively impact on design information coordination.

Findings from action research show that not only does the requirement need to be clearly defined, but also the output of the design information needs to be clearly produced for collaborative design development. Therefore, all the findings indicate the significance of this feature.

➢ <u>Information Precision on Building Design Quality</u>

The measurement of Information Clarity shows that with the quantity of sample (N=67), the Mean is calculated as 9.18 with Standard Deviation (SD) of 1.278. As the detailed statistics in (Table 5.3.2.c) show, the score ranges from 4 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.2.e). This research selects a 98% confidence level due to the findings from the focus group on the conceptual framework. Therefore, the confidential interval from the statistics shows the upper bound is 9.55 and the lower bound is 8.81. The Skewness of the normal distribution is -1.916 with Kurtosis of 3.849.

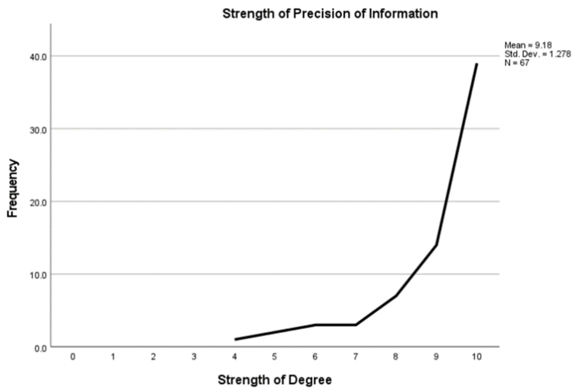


Figure 5.3.2. e

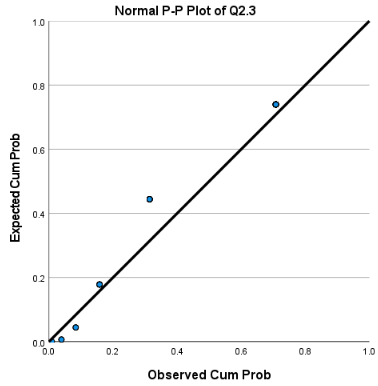


Figure 5.3.2. f

The P-P Plot shows that the normal distribution is closely aligned with the counted statistics, with points located near the diagonal curve (See Figure 5.3.2.f). Therefore, this result from the P-P Plot shows that the statistics are valid for acceptance. Hence, the strength of the (Information) Precision from the gamificative environment is accepted.

Table 5.3.2. c

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q2.3	Mean		9.18	0.156
	98% Confidence Interval for Mean	Lower Bound	8.81	
		Upper Bound	9.55	
	5% Trimmed Mean		9.34	
	Median		10.00	
	Variance		1.634	
	Std. Deviation		1.278	
	Minimum		4	
	Maximum		10	
	Range		6	
	Interquartile Range		1	
	Skewness		-1.916	0.293
	Kurtosis		3.849	0.578

According to the statistics, the findings show that the Information Precision of the information management in the gamificative environment has a strong impact on building design quality, because the Mean is (9.18), which is much higher than the expected value of (6).

The measurement of (Information) Precision of management in the gamificative environment through the survey shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing the design team to improve geometry management. Findings from the literature review (Cassano & Trani, 2017; Grytting et al., 2017; Uusitalo et al., 2019) show that graphical information is impacting on spatial and functional coordination in building project.
b) Allowing the design team to improve location management. Literature review of relevant area (Biljecki et al., 2016; Klakegg et al., 2020; Abouelkhier et al., 2021) shows that position is another important graphical information, which will impact on the quality of building design coordination.

Findings from action research show that high detail specifications such as LOD 350 can increase the precision of 3D information models for supporting project information management. Therefore, this feature generated from the gamificative environment does have strong impact.

➢ <u>Information Proficiency on Building Design Quality</u>

The measurement of Information Clarity from the survey shows that with the quantity of sample (N=67), the Mean is calculated as 9.15 with Standard Deviation (SD) of 1.294. As the detailed statistics in (Table 5.3.2.d) show, the score ranges from 5 to 10, and most frequencies are concentrated in 8 and 10 (See Figure 5.3.2.g). This research selects a 98% confidential level due to the findings from the focus group regarding the conceptual framework. Therefore, the confidential interval from the statistics shows the upper bound is 9.53 and the lower bound is 8.77. The Skewness of the normal distribution is -1.411 with Kurtosis of 1.109.

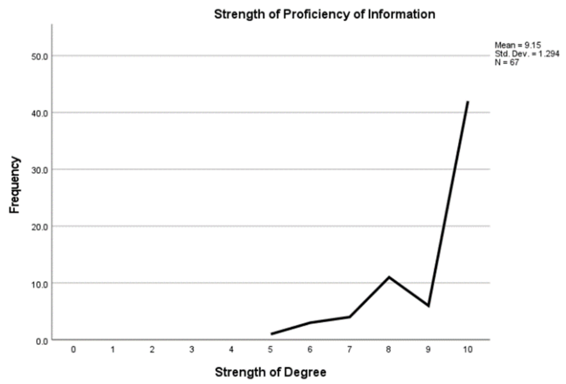


Figure 5.3.2. g

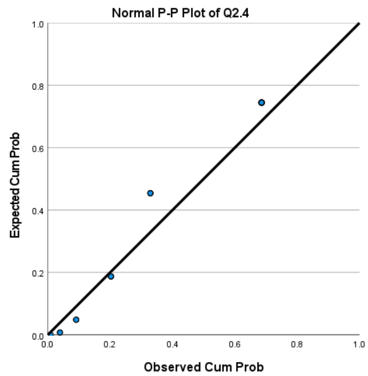


Figure 5.3.2. h

The P-P Plot shows that the normal distribution is closely aligned with the counted statistics, with points located near the diagonal curve (See Figure 5.3.2.h). Therefore, this result from the P-P Plot shows that the statistics are valid for acceptance. Hence, the strength of (Information) Proficiency from the gamificative environment is accepted.

Table 5.3.2. d

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q2.4	Mean		9.15	0.158
	98% Confidence Interval for Mean	Lower Bound	8.77	
		Upper Bound	9.53	
	5% Trimmed Mean		9.29	
	Median		10.00	
	Variance		1.674	
	Std. Deviation		1.294	
	Minimum		5	
	Maximum		10	
	Range		5	
	Interquartile Range		2	
	Skewness		-1.411	0.293
	Kurtosis		1.109	0.578

According to the statistics, the findings show that the Information Proficiency of information management in the gamificative environment has a strong impact on building design quality, because the Mean is (9.15), which is much higher than the expected value of (6).

The measurement of (Information) Proficiency of management in the gamificative environment through the survey shows the strength of this feature, which matches with the findings from the literature review as regards:

a) Allowing the design team to produce sufficient graphical information. Findings from the literature review (Abouelkhier et al., 2021; Hu et al., 2019; Boujaoudeh, 2019; Won & Cheng, 2017) show that the level of graphical detail will impact on team collaboration during design production.
b) Allowing the design team to produce sufficient non-graphical information. Literature reviews (Pikas et al., 2020; Arantes & Irizarry, 2017; Jupp, 2017; Prabhakaran et al., 2021) shows that non-graphical information is also impacting on building design coordination.

Findings from action research show that the proficiency of information is aligned with precision features of management in the gamificative environment. The implementation of LOD 350 has a great impact on the visualization process for design assessment and evaluation because the specification provides sufficient detail for design reference. Hence, the evidence confirms that this feature has a significant impact on a design management.

➢ <u>Information Consistency on Building Design Quality</u>

The measurement of Information Consistency from the survey shows that with the quantity of sample (N=67), the Mean is calculated as 8.97 with Standard

Deviation (SD) of 1.576. As the detailed statistics in (Table 5.3.2.e) show, the score ranges from 4 to 10, and most frequencies are concentrated at 8 and 10 (See Figure 5.3.2.g). This research has selected a 98% confidential level due to the findings from the focus group on the conceptual framework. Therefore, the confidence interval from the statistics shows the upper bound as 9.43 and the lower bound as 8.51. The Skewness of the normal distribution is -1.577 with Kurtosis of 1.689.

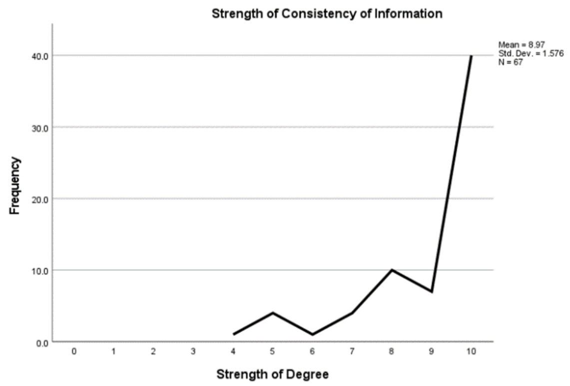


Figure 5.3.2. i

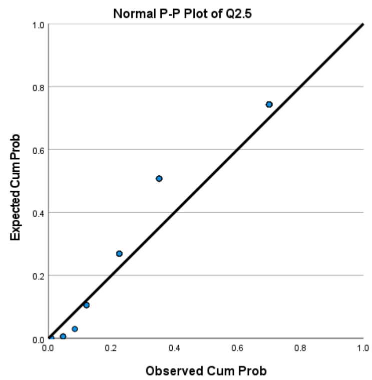


Figure 5.3.2. f

The P-P Plot show that the normal distribution is closely aligned with the statistics, with points located near the diagonal curve (See Figure 5.3.2.j). Therefore, the P-P Plot shows that the statistics are valid for acceptance. Hence, the strength of the (Information) Consistency on the gamificative environment is accepted.

Table 5.3.2. e

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q2.5	Mean		8.97	0.193
	98% Confidence Interval for Mean	Lower Bound	8.51	
		Upper Bound	9.43	
	5% Trimmed Mean		9.15	
	Median		10.00	
	Variance		2.484	
	Std. Deviation		1.576	
	Minimum		4	
	Maximum		10	
	Range		6	
	Interquartile Range		2	
	Skewness		-1.577	0.293
	Kurtosis		1.689	0.578

According to the statistics, the findings show that the Information Proficiency of information management within the gamificative environment has a strong impact on building design quality, because the Mean is (8.97), which is much higher than the expected value of (6).

The measurement of the (Information) Consistency of management within the gamificative environment through the survey shows the strength of this feature, which matches the findings from the literature review as regards:

a) Allowing the design team continuously developed project information. Findings from the literature review (Mataloto et al., 2020; Ghaffarianhoseini et al., 2017; Cardellicchio & Tombesi, 2021) show that the production of design details need to be arranged in a consistent manner to avoid chaos.
b) Allowing the design team to commonly share project information. The literature review (Gana et al., 2018; Ghaffarianhoseini et al., 2017; Park & Lee, 2017) shows the importance of a mutual accessed project data environment in team collaboration.

Findings from action research show that consistency of project information can speed up project development and can aid efficient decision-making for the delivery process. Therefore, all the evidence highlights the importance of this feature of design management in the gamificative environment.

Table 5.3.2. f

	Building Design Quality
Reliability	Determine if the project data are correct.
Clarity	Determine if the design production is appropriate.
Precision	Determine if the detail level is suitable.
Proficiency	Determine if the information quantity is sufficient.
Consistency	Determine if the project development is well distributed.

Therefore, the statistical results show that all five features of information modelling and management within the gamificative environment have a strong impact on information coordination during building design development (See Table 5.3.2.f). The findings from the literature review regarding the impact of (Information) Reliability, (Information) Clarity, (Information) Proficiency, (Information) Precision, and (Information) Consistency match the findings from the quantitative data collected from the survey results. There is some linkage among the five features; the reliability of information is the foundation of design production, followed by clarity, proficiency, and information precision. Finally, all the information needs to be consistently organized for information management effectiveness.

Table 5.3.2. g

	Reliability	Clarity	Precision	Proficiency	Consistency
Mean	9.00	9.04	9.18	9.15	8.97
SD	1.403	1.261	1.278	1.294	1.576

(Table 5.3.2.g) summarises the statistics regarding the strength of information modelling and management in the gamificative environment. From the results, it can be seen that all five features of information management have a high Mean, with the Standard Deviation (SD) around 1.500. Therefore, this shows that the data collected from the survey are very stable, meaning opinions are stable, representing the strength of information management features in the gamificative environment.

5.3.3 Strength of Production Capabilities

In this section, the research discusses the quantitative data analysis results to argue the impact of improved building design production capability on the business operation of building design companies. The data discussion has the same approach as Sections 5.3.1 and Section 5.3.2.

5.3.3.1 Resource Capability Impact on Business Operation

Resource capability is classified as Technical Skills and Human Interaction Capability, based on findings from the literature review and action research

- Technical Skill Capability

The findings, of, the descriptive statistical analysis of Technical Skill Capability, using SPSS software, are shown in (Table 5.3.3.a). The Mean is 8.51 with a Standard Deviation (SD) of 2.018 and sample quantity (N=67). The score range is from 0 to 10, and most frequencies are concentrated between 8 and 10 (See Figure 5.3.3.a). With a 98% confidence, the upper bound is 9.10 and the lower bound is 7.92. The statistics show that the Skewness of the normal distribution is -1.961 and the Kurtosis is 4.802.

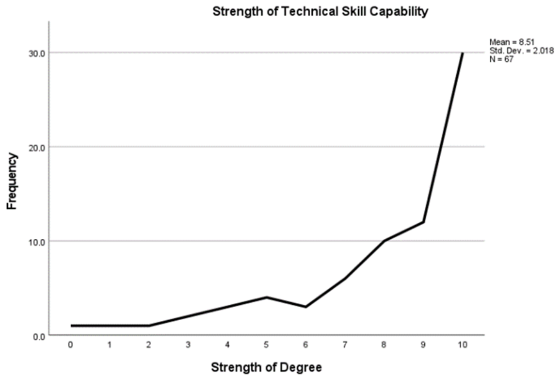


Table 5.3.3. a

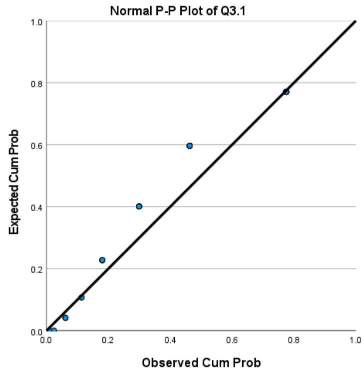


Table 5.3.3. b

The P-P Plot used to validate the acceptance of the data (Figure 5.3.3.b) shows that the normal distribution is a close match to the actual data through the single diagonal line. Therefore, this research considers that Technical Skill in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. a

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.1	Mean		8.51	0.247
	98% Confidence Interval for Mean	Lower Bound	7.92	
		Upper Bound	9.10	
	5% Trimmed Mean		8.75	
	Median		9.00	
	Variance		4.072	
	Std. Deviation		2.018	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-1.961	0.293
	Kurtosis		4.802	0.578

The results from the statistical analysis show that the impact of Technical Skills on building design business operation is high, with a Mean of (8.51), which is much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

➢ Human Interactive Capability

The descriptive statistical analysis of Human Interactive Capability is shown in (Table 5.3.3.b)., With a quantity sample of (N=67), the Mean is 8.36 with a Standard Deviation (SD) of 2.172. The score range is from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.c). With a confidential level of 98%, the upper bound is 8.99 and the lower bound is 7.73. The statistics show that the Skewness of the normal distribution is -1.722 and Kurtosis 3.151.

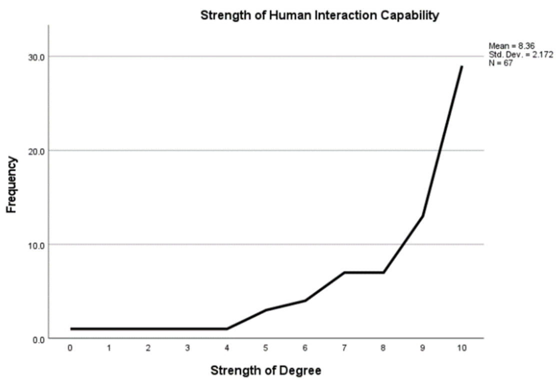


Figure 5.3.3. c

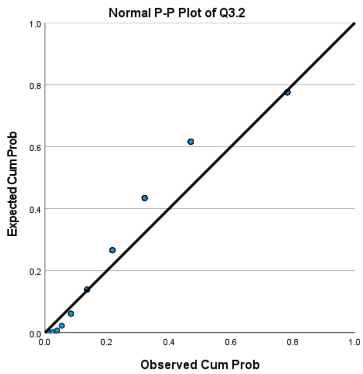


Figure 5.3.3. d

The P-P Plot is used to validate the acceptance of data. (Figure 5.3.3.d) shows that the normal distribution closely matches the actual data through the single diagonal line. Therefore, this research considers that the Human Interaction Capability in the gamificative environment has a strong impact on business operation of building design companies.

Table 5.3.3. b

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.2	Mean		8.36	0.265
	98% Confidence Interval for Mean	Lower Bound	7.73	
		Upper Bound	8.99	
	5% Trimmed Mean		8.63	
	Median		9.00	
	Variance		4.718	
	Std. Deviation		2.172	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		3	
	Skewness		-1.722	0.293
	Kurtosis		3.151	0.578

The results from the statistical analysis show that the impact of Human Interactive Capability on building design business operation is high, with a Mean of (8.36), much higher than the defined value of (6). The results meet with the statistical standards for acceptance.

The measurement of Resource Capability of building design production in the gamificative environment shows the strength of this capability, which matches the findings from the literature review as regards:

a) Allowing the design team to better handle advanced production technologies. The findings from the literature review (Brown, 2020; Latini, 2021; Guo et al., 2020; Pratama & Dossick, 2019; Xiao, 2019) show that the technology advancement can enable design team to better visualize and coordinate the project data.
b) Allowing the design team to be better involved in building design production. The literature review (Deterding, 2019; Saheem & Festing, 2020; Kim, 2018; Norman, 2017; Rodriguez et al., 2016) shows the implementation of advanced technologies needs to focus on end-users' experience.

Findings from action research show the importance of technical skills of the design team when interacting with the virtual environment. Also, the findings highlight the significance of interactive technology in information coordination. Therefore, all the findings focus on the strength of resource capability within the gamificative environment.

5.3.3.2 Decision-Making Capability Impact on Business Operation

Based on the findings from the literature review and action research, Decision-Making Capability includes Forecast Capability and Executive Bespoke Request Capability.

- Forecast Capability

The findings from the statistics of the descriptive statistical analysis regarding Forecast Capability, using SPSS software, are shown in (Table 5.3.3.c). With a sample quantity of (N=67), the Mean is 8.57 and Standard Deviation (SD) 2.024. The score ranges from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.e). With a confidence level of 98%, the upper bound is 9.16 and the lower bound is 7.98. The statistics show that the Skewness of the normal distribution is -1.993 and Kurtosis 4.642.

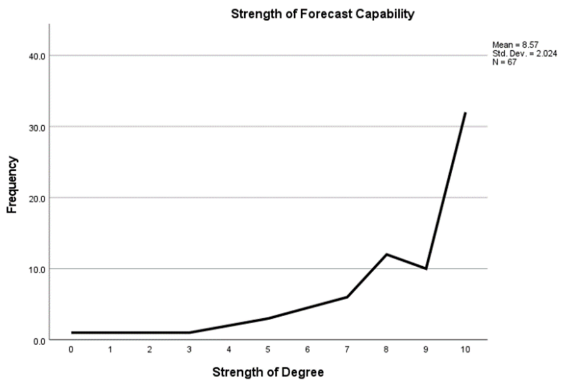


Figure 5.3.3. e

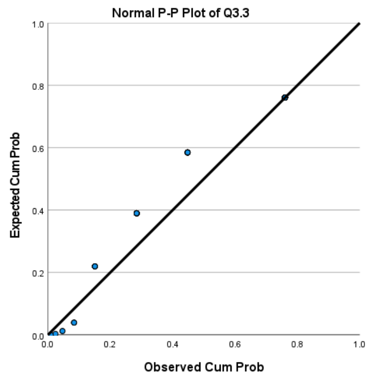


Figure 5.3.3. f

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.f) shows that the normal distribution is closely matched with the actual data through the single diagonal line. Therefore, this research considers that the Forecast Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. c

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.3	Mean		8.57	0.247
	98% Confidence Interval for Mean	Lower Bound	7.98	
		Upper Bound	9.16	
	5% Trimmed Mean		8.82	
	Median		9.00	
	Variance		4.098	
	Std. Deviation		2.024	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-1.993	0.293
	Kurtosis		4.642	0.578

The results from the statistical analysis show that the impact of Forecast Capability on building design business operation is high, with a Mean of (8.57), which is much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

- Executive Bespoke Capability

The descriptive statistical analysis of Executive Bespoke Capability is shown in (Table 5.3.3.d). With a quantity sample of (N=67), the Mean is 8.58 and Standard Deviation (SD) 1.947. The score ranges from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.g). With a confidential level of 98%, the upper bound is 9.15 and the lower bound is 8.01. The statistics show that the Skewness of the normal distribution is -2.050 with Kurtosis 5.426.

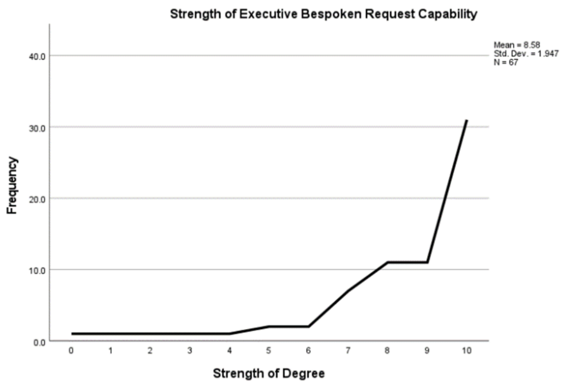


Figure 5.3.3. g

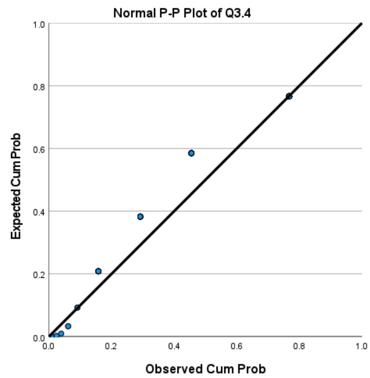


Figure 5.3.3. h

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.h) show the normal distribution is closed matched with the actual data through the single diagonal line. Therefore, this research considers that the Executive Bespoken Capability within a gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. d

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.4	Mean		8.58	0.238
	98% Confidence Interval for Mean	Lower Bound	8.01	
		Upper Bound	9.15	
	5% Trimmed Mean		8.83	
	Median		9.00	
	Variance		3.792	
	Std. Deviation		1.947	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.050	0.293
	Kurtosis		5.426	0.578

The results from the statistical analysis show that the impact of Executive Bespoken Capability on building design business operation is high, with a Mean of (8.58), which is much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

The measurement of the Decision-Making Capability of the building design production within the gamificative environment through the survey shows the strength of this capability, which matches the findings from the literature review as regards:

a) Allowing the project team to increase the capability of the building simulation. The findings from the literature review (Andreini & Bettinelli, 2017; Espinosa & Zarruk, 2021; Lim, 2017; Tomasz & Andrzej, 2016) show the increased decision-making will allow company to deliver the project in an efficient way.
b) Allowing the project team increased response to requests. The findings (Hugo et al, 2022; Knotten et al., 2017; Park et al., 2017) show that the efficient action will allow companies to handle more tasks at same time for

increasing the productivities.

Findings from action research show that simulation and response in the gamificative environment impact capability of project forecasting, which enables relevant action for design modification, thus improving efficiency in design production. Therefore, all the results indicate the importance of decision-making during design business operation.

5.3.3.3 Collaboration Capability Impact on Business Operation

Based on the findings from the literature review and action research, Collaboration Capability includes Internal Collaboration Capability and External Collaboration Capability.

- Internal Collaboration Capability

The findings from the statistics of Internal Collaboration Capability, using SPSS software, are shown in (Table 5.3.3. e). With a sample quantity of (N=67), the Mean is 8.81 and Standard Deviation (SD) is 2.009. The score ranges from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.i). With a confidential level of 98%, the upper bound is 9.39 and the lower bound is 8.22. The statistics show that the Skewness of the normal distribution is -2.428 with Kurtosis 6.750.

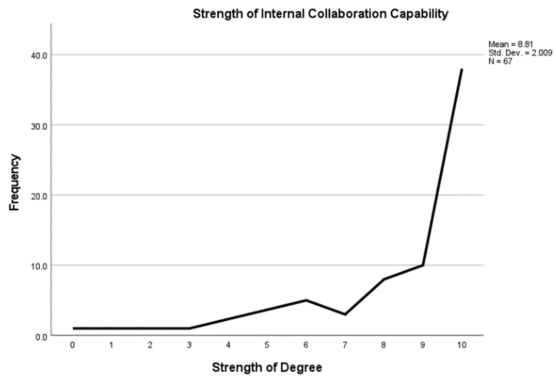


Figure 5.3.3. i

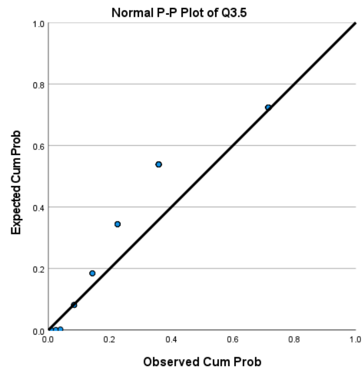


Figure 5.3.3. j

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.j) shows that normal distribution is closely matched with the actual data through the single diagonal line. Therefore, this research considers that Internal Collaboration Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. e

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.5	Mean		8.81	0.245
	98% Confidence Interval for Mean	Lower Bound	8.22	
		Upper Bound	9.39	
	5% Trimmed Mean		9.11	
	Median		10.00	
	Variance		4.038	
	Std. Deviation		2.009	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.428	0.293
	Kurtosis		6.750	0.578

The results from the statistical analysis show that the impact from Internal Collaboration Capability on building design business operation is high, with a Mean of (8.81), much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

➢ External Collaboration Capability

The descriptive statistical analysis of External Collaboration Capability is shown in (Table 5.3.3.f). With a sample quantity of (N=67), the Mean is 8.66 with Standard Deviation (SD) of 2.049. The score ranges from 0 to 10, with most frequencies concentrated in 8 and 10 (See Figure 5.3.3.k). With a confidential level of 98%, the upper bound is 9.25 and the lower bound is 8.95. The statistics have shown that the Skewness of the normal distribution is -2.176 with the Kurtosis of 5.491.

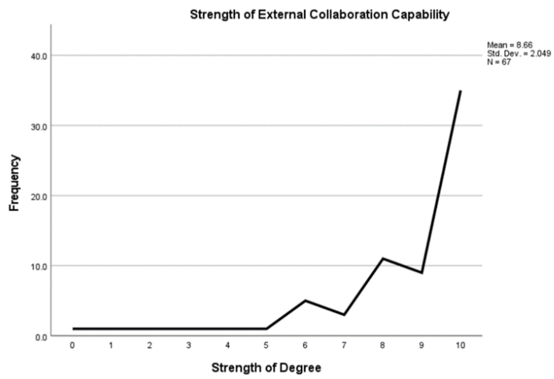


Figure 5.3.3. k

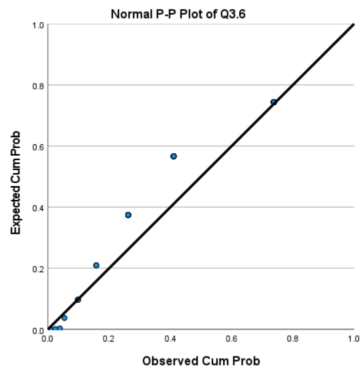


Figure 5.3.3. l

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.l) shows that the normal distribution is closed matched with the actual data through the single diagonal line. Therefore, this research considers that External Collaboration Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.4.3. f

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.6	Mean		8.66	0.250
	98% Confidence Interval for Mean	Lower Bound	8.06	
		Upper Bound	9.25	
	5% Trimmed Mean		8.95	
	Median		10.00	
	Variance		4.199	
	Std. Deviation		2.049	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.176	0.293
	Kurtosis		5.491	0.578

The results from the statistical analysis show that the impact of External Collaboration Capability on building design business operation is high, with a Mean of (8.66), much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

The measurement of Collaboration Capability of building design production in the gamificative environment through the survey shows the strength of this capability, which matches with the findings from the literature review as regards:

a) Allowing the design team better coordination between each discipline. Findings from the literature review of the relevant studies (Kapogiannis & Sherratt, 2017; Oraee et al., 2017; Latini, 2021; Zaker & Coloma, 2018) show that collaborative technologies can improve the coordination in project team for enhancing the productivities.
b) Allowing the design team better agreement with clients and stakeholders. According to the literature review (Pradabwong et al., 2017; Tayeh & Issa, 2020; Lou et al., 2019; Almeida, et. al., 2019), the efficiencies of decision-makings can be impacted by adopting collaborative technologies.

Findings from action research show that through use of different collaborative technologies in the gamificative environment, the performance of both internal and external collaboration is improved. Thus, with validation through the survey results, collaboration capability within the gamificative environment has a strong impact on building design business operation.

5.3.3.4 Communication Capability Impact on Business Operation

Communication capability is categorized into Clients and Designer Expressing Capability and Understanding Capability, based on the findings from the literature review and action research.

- Clients and Designer Expressing Capability

Findings from the statistics in the descriptive statistical analysis from the survey regarding Client and Designer Expressing Capability, using SPSS software, are shown in (Table 5.3.3.g). With a sample quantity of (N=67), the Mean is 8.97 and Standard Deviation (SD) is 1.660. The score range is from 2 to 10, with most frequencies concentrated between 9 and 10 (Figure 5.3.3.m). With a confidential level of 98%, the upper bound is 9.45 and the lower bound is 8.49. The statistics show that the Skewness of the normal distribution is -2.040 and Kurtosis 4.540.

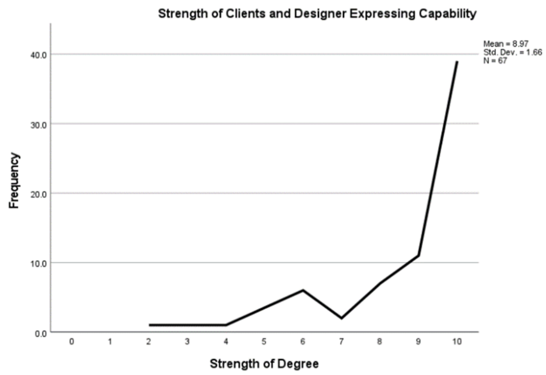


Figure 5.4.3. m

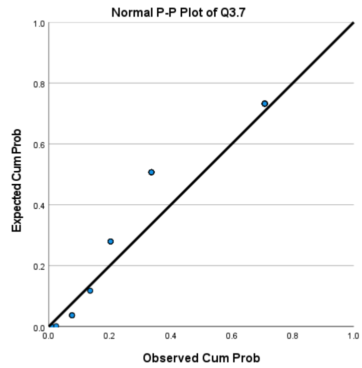


Figure 5.4.3. n

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.n) shows that the normal distribution is closely matched with the actual data through the single diagonal line. Therefore, this research considers that the Clients and Designer Expressing Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. g

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.7	Mean		8.97	0.203
	98% Confidence Interval for Mean	Lower Bound	8.49	
		Upper Bound	9.45	
	5% Trimmed Mean		9.18	
	Median		10.00	
	Variance		2.757	
	Std. Deviation		1.660	
	Minimum		2	
	Maximum		10	
	Range		8	
	Interquartile Range		2	
	Skewness		-2.040	0.293
	Kurtosis		4.540	0.578

The results from the statistical analysis show that the impact of Clients and Designer Expressing Capability on building design business operation is high, with a Mean of (8.97), much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

- ➢ Understanding Capability

The descriptive statistical analysis regarding Understanding Capability is shown in (Table 5.3.3.h). With a sample quantity of (N=67), the Mean is 8.66, with a Standard Deviation (SD) of 2.049. The score ranges from 0 to 10, with most frequencies concentrated in 8, 9, and 10 (See Figure 5.3.3.o). With a confidence level of 98%, the upper bound is 9.30 and the lower bound is 8.07. The statistics show that the Skewness of the normal distribution is -2.154 with Kurtosis 5.026.

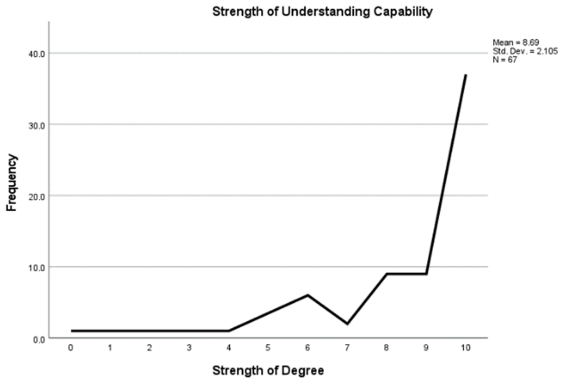


Figure 5.3.3. o

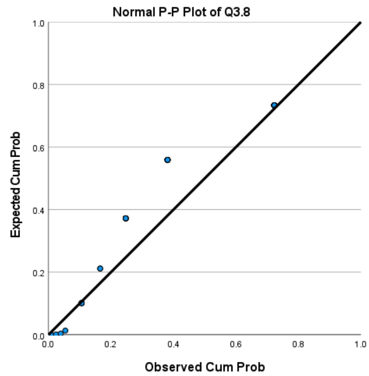


Figure 5.3.3. p

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.p) shows that the normal distribution is closed matched with the actual data through the single diagonal line. Therefore, this research considers that the Understanding Capability within the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. h

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.8	Mean		8.69	0.257
	98% Confidence Interval for Mean	Lower Bound	8.07	
		Upper Bound	9.30	
	5% Trimmed Mean		8.99	
	Median		10.00	
	Variance		4.431	
	Std. Deviation		2.105	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.154	0.293
	Kurtosis		5.026	0.578

The results from the statistical analysis show that the impact of Understanding Capability on building design business operation is high, with a Mean of (8.69), much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

The measurement of Communication Capability of the building design production in the gamificative environment through the survey shows the strength of this capability, which matches the findings from the literature as regards:

a) Allowing the design team to better present the project design to different project participants. The findings from the literature review (Zhao, 2020; Bosch et al., 2019; Tayeh & Issa, 2020; Bell & Martin, 2019) show that the improved understandings can impact on decision-making efficiencies.
b) Allowing the project team increased confidence regarding design development. According to the literature review (Reyes, 2021; Polack, 2020; Pikas et al., 2018; Lawson, 2020), the decision-making efficiencies is depending on the confidence toward project development.

Findings from action research show that the implementation of a gamificative environment improves communication between the design team and stakeholders, increasing he expression and understanding, enhancing confidence toward the project. Therefore, all the results show that communication capability within the gamificative environment strongly impacts the building design business operation.

5.3.3.5 Management Capability Impact on Business Operation

Based on the findings from the literature review and action research, Management Capability includes Planning Capability and Organizational Capability.

- Planning Capability

Findings from statistics on the descriptive statistical analysis from the survey of Planning Capability, using SPSS software, are shown in (Table 5.3.3.i). With a sample quantity of (N=67), the Mean is 8.58 with a Standard Deviation (SD) of 2.090. The score range is from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.q). With a confidence level of 98%, the upper bound is 9.19 and the lower bound is 7.97. The statistics show that the Skewness of the normal distribution is -1.997, with Kurtosis 4.414.

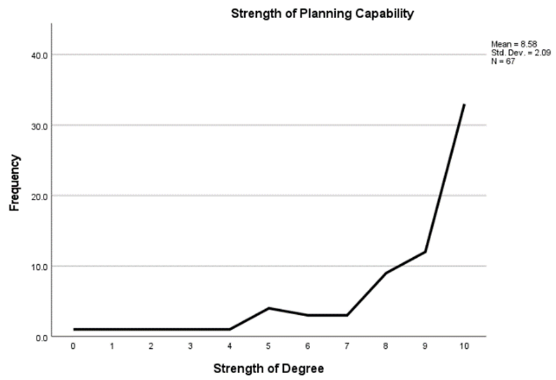


Figure 5.3.3. q

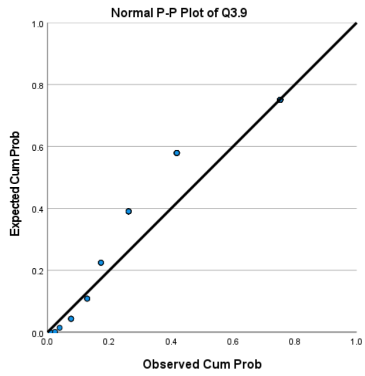


Figure 5.3.3. r

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.r) shows the normal distribution closely matches with the actual data through the single diagonal line. Therefore, this research considers that the Planning Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. i

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.9	Mean		8.58	0.255
	98% Confidence Interval for Mean	Lower Bound	7.97	
		Upper Bound	9.19	
	5% Trimmed Mean		8.85	
	Median		9.00	
	Variance		4.368	
	Std. Deviation		2.090	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-1.997	0.293
	Kurtosis		4.414	0.578

The results from statistical analysis show that the impact of Understanding Capability on building design business operation is high with the Mean of (8.58), which is much higher than the defined value of (6). The results meet the statistical standard for acceptance.

- Organizational Capability

The descriptive statistical analysis regarding Organizational Capability is shown in (Table 5.3.3.j). With a sample quantity of (N=67), the Mean is 8.70 and Standard Deviation (SD) is 2.209. The score ranges from 0 to 10, with most frequencies concentrated between 8 and 10 (See Figure 5.3.3.s). With a confidential level of 98%, the upper bound is 9.34 and the lower bound is 8.06. The statistics show that the Skewness of the normal distribution is -2.495, with Kurtosis 6.809.

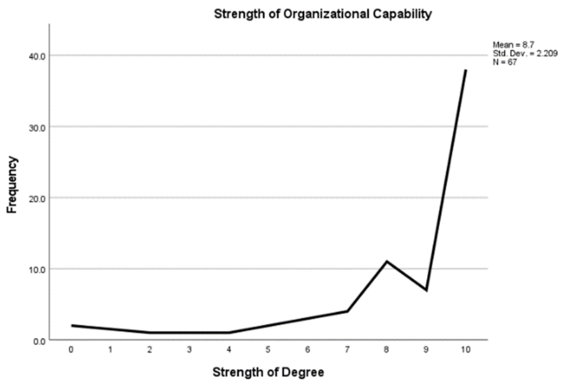


Figure 5.3.3. s

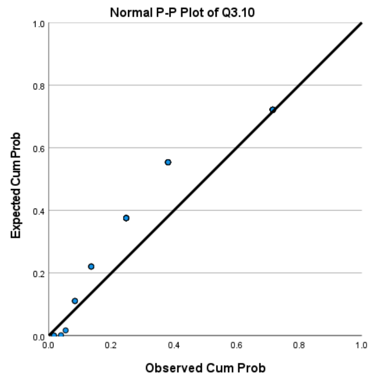


Figure 5.3.3. t

The P-P Plot is used to validate the acceptance of the data. (Figure 5.3.3.t) shows that the normal distribution is closely matched with the actual data through the single diagonal line. Therefore, this research considers that the Organizational Capability in the gamificative environment has a strong impact on the business operation of building design companies.

Table 5.3.3. j

Descriptive Statistical Analysis				
			Statistic	Std. Error
Q3.10	Mean		8.70	0.270
	98% Confidence Interval for Mean	Lower Bound	8.06	
		Upper Bound	9.34	
	5% Trimmed Mean		9.06	
	Median		10.00	
	Variance		4.879	
	Std. Deviation		2.209	
	Minimum		0	
	Maximum		10	
	Range		10	
	Interquartile Range		2	
	Skewness		-2.495	0.293
	Kurtosis		6.809	0.578

The results from the statistical analysis show that the impact of Organizational Capability on building design business operation is high, with a Mean of (8.70), much higher than the defined value of (6). The results meet with the statistical standard for acceptance.

The measurement of Management Capability of building design production in the gamificative environment through the survey shows the strength of this capability, which match the findings from the literature review as regards:

a) Allowing the design team to better control the production schedule. According to the literature reviews (Cross, 2019; Kerpedzhiev et al., 2021; Gao et al., 2020; Bjørn et al., 2021; Uusitalo et al., 2018), improved capability in scheduling will help design team to increase the productivities to enhance business operation performance.
b) Allowing the design company to better allocate production technical resources. The findings from the relevant research (Kerpedzhiev et al., 2020; Antonucci et al., 2021; Nordin et al., 2018; Guo et al., 2020; Caputo et al., 2019) show that capital resource allocation will help companies to optimize

the production for enhancing business operation.

Findings from action research show that the adoption of a gamificative environment impacts the capability to increase control of the design production schedule, led by the capability of resource management from the conceptual framework. Therefore, all the evidence points to the importance of management capability during building design development.

Table 5.3.3. k

Business Operation Capability	
Resource	Advanced production tools during the building design
Decision-Making	To improve the efficiencies of the delivery process
Collaboration	To ensure the quality of the design production
Communication	To meet with the relevant design requirements and regulations
Management	To determine the overall building design efficiencies

With the findings from the statistics of the survey results, this research finds that all five capabilities generated in the gamificative environment have a strong impact on building design business operation. These capabilities comprise Resource Capability, Decision Making Capability, Collaboration Capability, Communication Capability, and Management Capability (Figure 5.3.3.k). The findings from the literature review show that these capabilities are linked with design production capabilities, which is associated with improving the business operation of building design companies. Design management relies on collaboration and communication capabilities, which contribute to decision-making capability. All business operations need the capability of resource allocation; hence IT skills for interaction determine the success of the building project.

Table 5.3.3. l

	Resource Capability		Decision-Making Capability	
	Technical Skills	Human Interaction	Precast	Executive Bespoken
Mean	8.51	8.36	8.57	8.58
SD	2.018	2.172	2.024	1.947
	Internal	External	Expressing	Understanding

	Collaboration	Collaboration		
Mean	8.81	8.66	8.97	8.69
SD	2.009	2.094	1.660	2.105
	Planning	Organizational		
Mean	8.58	8.70		
SDs	2.090	2.209		

(Table 5.3.3.l) shows the statistic results of each capability within the gamificative environment that impact building design business operation. The strength of all ten capabilities is scored between 8 and 9, higher than the expected score of 6. The results show that the Standard Deviation (SD) of the features is around 2.000. Although not as stable as those results in section 5.3.1 and 5.3.2, they are still acceptable in terms of strength of impact. One thing observed from the data through (Table 5.3.3.l), compared with data in (Table 5.3.1.g) and (Table 5.3.2.g), is that the score is relatively low, and the SD is a little high. The research will be discussed later in this chapter.

5.4 Findings and Limitations

5.4.1 Findings from Data Discussion

Based on the findings from the data discussion, this research has identified that business operation performance of building design companies is dependent on the quality of the design and the efficiencies of information coordination, which is the design production capability. According to the findings, information coordination depends on the efficiencies of communication and the efficiencies of problem detection. It is agreed that the convenience and efficiencies of data accessibility will impact the information coordination process. Hence, the role of the Common Data Environment (CDE) in building design development is verified.

During the analysis of the collected data, this research has identified that many people are concerned about the perceived difficulties of gamificative technologies; it is believed that extra time is required for learning and that this kind of technology cannot be widely adopted in the short to medium term. The findings verify that the use of technology is highly reliant on people and process; only if people know how to properly use the relevant technology through correct Standard, Methods, and Procedures (SMPs) can the technology impact those factors during information coordination.

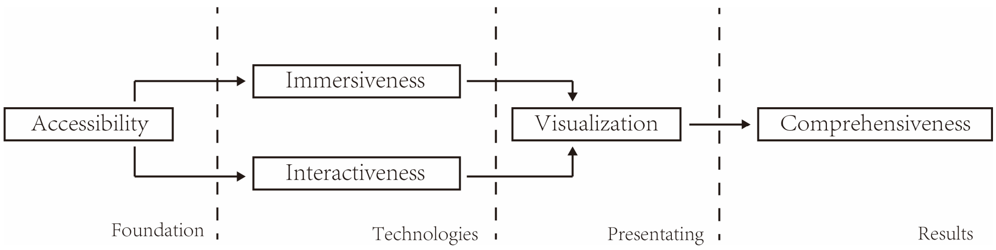


Figure 5.4 a: Interrelation to Impact Information Coordination

With the findings from the literature review and action research, both focus group and survey validate the strength of the features of a gamificative environment's impact on information coordination of building design development. (Figure 5.4.a) shows the interrelation between each feature. The entire structure is categorized into four layers: foundation, technologies, presenting, and results. The (data) accessibility is the most important aspect of information coordination, while access to project data, interactive and immersive technologies can work together for comprehensive visualization to increase project information coordination.

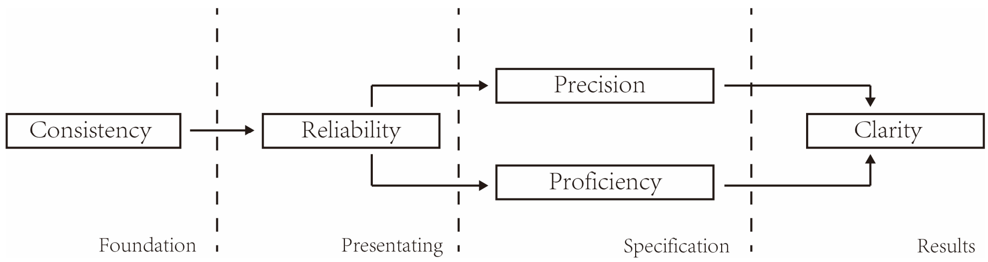


Figure 5.4 b: Interrelation to Impact Design Quality

Once the project information is correctly and sufficiently coordinated, the quality of the building design can be improved. (Figure 5.4.b) illustrates the interrelation between different features of information development, also categorised into four levels. The consistency of the information is the foundation because it ensures all the incoming information is reliable for further development, such as precision and proficiency. Once all the information is correctly developed and coordinated, it can provide information clarity for the assessment and reviewing process.

Although most people are in agreement that the proposed conceptual framework can impact information coordination, design quality, and building design business operation, there are still significant concerns regarding cost; substantial investment is required for implementing the proposed solution, largely for IT mobilization and personnel training. Therefore, this finding indicates that this conceptual framework might need long-term development; hence, relevant resources and activities of business operation need to be considered for achieving the expected outcomes.

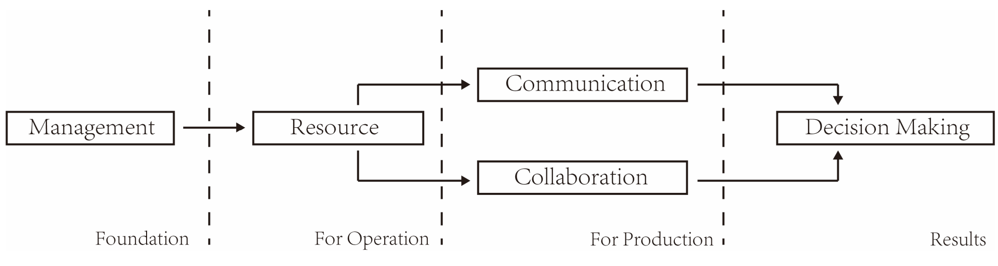


Figure 5.4 c: Impact of Interrelation on Impact Business Operation

The findings of how information coordination and building design quality are associated with different features shows their capability for enhancing the business operation of building design companies. (Figure 5.4.c) shows how the connection between different capabilities, IT management skills, and human interaction capabilities, impacts the production of building design development for enhanced decision making. Improved decision making can accelerate delivery efficiencies and hence, design productivity can be increased.

The findings from the focus group discussion show that collaboration is impacted by technology, which indicates that support from technical solutions impacts information coordination. It also indicates that technology will change the development of building design. One of these collaborative technologies is the Common Data Environment (CDE), whose advantages are explored through the literature review and which is put into practice in the action research. However, due to its complexity and lack of sophistication, its development for full adoption is some way off.

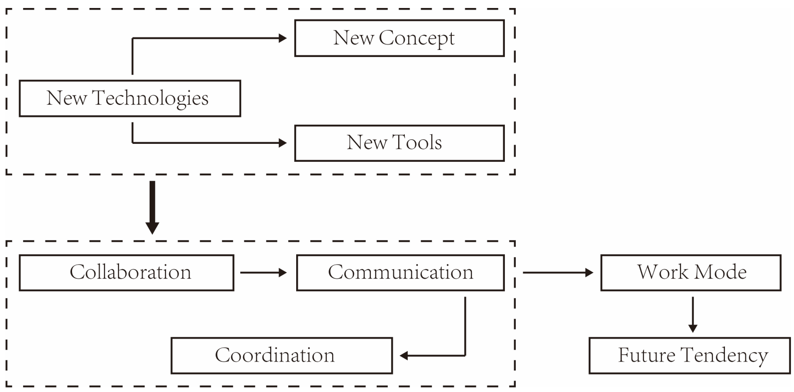


Figure 5.4 d: Future way of Collaboration

As identified from the literature review, business operation performance depends on its core capability in production, and production capability relies on its collaboration in the project team and with stakeholders. The technology is categorized into two parts: concept and tools. This research has identified that gamificative technology impacts the collaborative process under the proposed conceptual framework due to data accessibilities, data exchangeability, and data visibility. (Figure 5.4.d) shows that collaboration is impacted by new technology, and can lead to a new work mode in the long-term. The findings from the data analysis show that information coordination is impacted by communication, and the quality of communication depends on collaboration.

According to the data discussion, three aspects need to be impacted by the features of the gamificative environment through adopting the proposed gamificative technologies through the intervention studies in action research: information coordination, design quality, and business operation. Information coordination is mainly impacted by consistent access to the appropriate project data; the quality of building design relies on appropriately developed data; and business operation relies on the project design being efficiently delivered. The features of the conceptual framework impact on the consistent access to project data, which leads to improved management of project information. With the generated capabilities, the business operation of building design companies could handle the project in a better way to enhance productivity.

The third research objective is how information coordination can impact on the business operation of the building design (Figure 5.4.e). The requirement of information coordination needs the support of business operation to acquire the demanded resource for allocating the facilities and equipment in IT mobilization. Also, it requires building design activities to follow the SMPs during the modelling and visualization process of BIM implementation. On this basis, the proposed solution for building design business operation is using gamification to create a gamificative environment for increasing the interaction between people and virtual environment during the building design process. Through such an immersive and dynamic visualized environment, the design can be better understood by project participants for taking decisions regarding spatial and functional coordination, thus increasing building design quality.

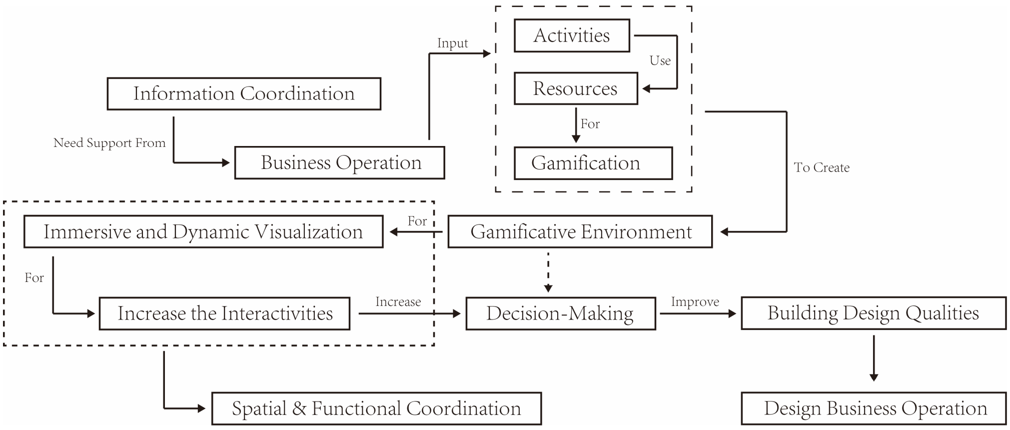


Figure 5.4 e: Information Coordination Impact on Business Operation

Beginning with the business operation, the resource and facilities relate to the implementation of technology, while activities are directly linked with design and modelling based on the findings of qualitative data. The reason that resources and facilities are being linked with AEC technologies is because creation of a gamificative environment requires the support of certain hardware and software; to purchase these tools is a significant operational cost in the design business. The impact of business operation and technology on building design development depends on the quality of 3D information modelling at the design and modelling stage. This stage is highly impacted by visualization solutions. Based on the quality of 3D models, project participants can better utilize BIM strategies to improve the building design process. Improved building design quality can impact business operation owing to improved production capability.

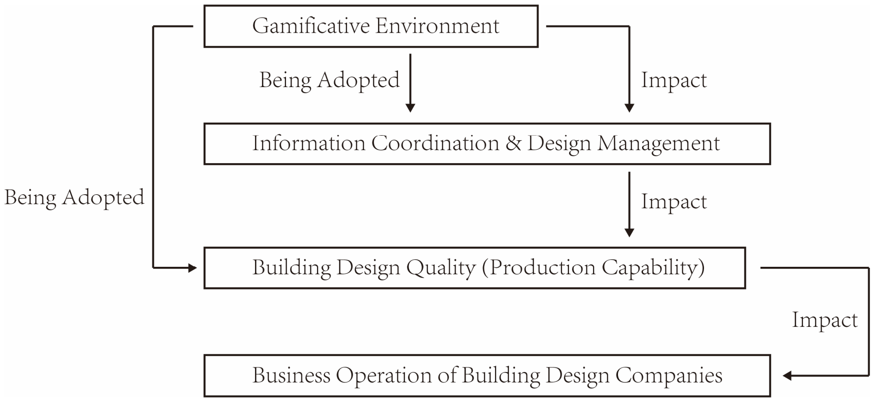


Figure 5.4 f: Impact of the Gamificative Environment on Business Operation

(Figure 5.4.f) shows the validation results from the primary data analysis regarding the impact of the gamificative environment on the business operation of building design companies. The results show that information coordination and design management are impacted by the gamificative environment, while information coordination and design management in the gamificative environment impacts the quality of building design. With the improved design quality, production capability is increased, enhancing business operation performance.

5.4.2 Limitations and Future Development

According to the findings from the literature review, action research, focus group discussion, and survey, this research has identified that the limitation of the proposed conceptual framework is focused on the technical aspect of the Common Data Environment (CDE). Although current available CDE can enable data to be carried on a cloud-based drive for visualization and commenting, the CDE does not support the entire project development from planning to modification. All relevant modification requests need to be submitted via an extra process for modifying the design and modelling software, output again and uploaded to the cloud for additional reviewing. This process will take extra time and workload, which may lead to inconsistency of data accessibility and exchangeability. Based on the findings of this research, CDE is the most important aspect of this conceptual framework since it is the carrier of the data, including all the data development and exchange. Therefore, CDE has a strong impact on collaboration.

The key aspect repeatedly discussed in the focus group is how each discipline in the design team can coordinate the information simultaneously in one environment for increasing efficiency. Although the proposed conceptual framework provides a good guideline for enhancing the collaborative environment to improve the building design qualities, there is still a need to improve the technical solutions for enabling real time design modification requests. If the relevant CDE platform can provide the connection to the design and modelling software, the information coordination will improve significantly. Therefore, CDE needs to be a database for connecting both design software and visualization platform for improved information management for building project development.

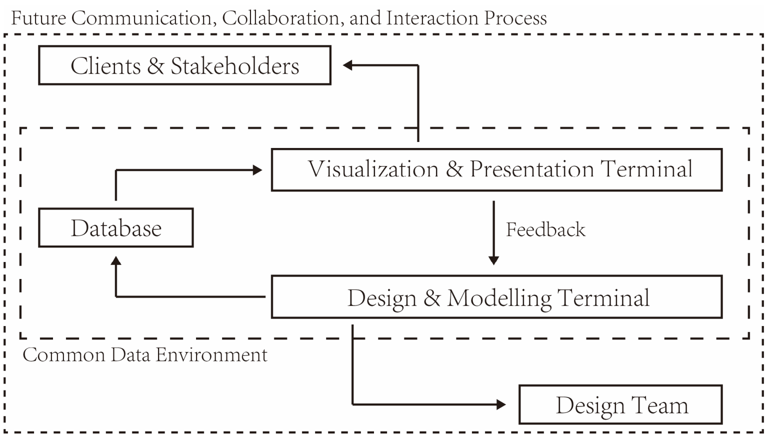


Figure 5.4 g: Proposed Project Development

Hence, this research argues that in order to efficiently implement this conceptual framework in the building design process, there needs to be some improvement of the current CDE as regards capabilities to deal with the real-time online modification for avoiding unnecessary time delay. (Figure 5.4.g) presents the desired structure of CDE for connecting the design platform and visualization tool via a unified database. The design team can directly conduct the design and modelling process in the CDE, and all the data will be stored in the cloud-based database. The visualization tool extracts data from this database for creating an immersive environment to support decision making. The relevant feedback can be directly addressed by the design team in CDE. Therefore, the interaction established by the gamificative environment can efficiently be practiced during the building design development.

Another concern raised during the discussion is that the gamificative environment needs to be focused more on BIM implementation rather than interaction with the virtual environment. The solution given by the proposed conceptual framework in the gamificative environment is to rely on the quality of a 3D information model for increasing realistic visualization development. Therefore, it come again with the specification of Level of Development. At the start of the research, each specification of LOD was discussed through the literature review. The role of LOD provides a guideline for developing a suitable detailed model to support the design process. Modelling is part of the strategies for design development; therefore, the immersive and dynamic visualization environment relies on sufficient model detail. Hence, although the gamificative environment can increase interaction between people and design process, the quality of the 3D information model development has a strong impact on provision of technical support.

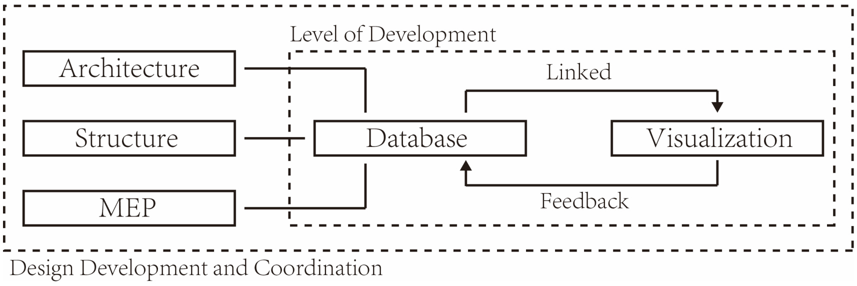


Figure 5.4 h: Proposed CDE Structure

For better integrating design and modelling data for project design development, the future role of CDE needs to integrate each discipline' s data directly to the database for coordination, visualization, and presentation purposes. (Figure 5.4.h) shows the relations between each of the items. The database is directly linked with data from each of the disciplines, and visualizes these data for evaluation purposes. The data constructed in the database follows LOD specifications to ensure valid information coordination. Relevant feedback from assessment can be added to the database for the design team, to be modified directly via the cloud environment. Hence, the core of the CDE in future software development will be focused on how the database can link all functions together for dealing with faster modification requests.

5.5 Final Conceptual Framework

5.5.1 Review of Previous Findings

The first stage of the conceptual framework is developed based on the findings in the literature reviews regarding issues in building design information coordination. The identified features in LOD 350, ISO 19650, and Gamification has been linked with those factors of information coordination. The conceptual framework at this stage is in its infancy; an immersive and interactive environment for visualization is proposed, by integration with LOD 350 and ISO

19650, to improve the coordination of building design information. ISO 19650 regulates how information needs to be produced and managed while LOD 350 specifies the detail level of data development. From the literature review, this research has also identified that the immersive and interactive environment depends on the support of relevant technologies.

For a more comprehensive exploration of how information coordination can be improved by the proposed solution, the action research used three different technical approaches in three different types of AEC projects to observe whether and how the proposed conceptual framework under different gamificative technologies could impact factors of information coordination. Based on the findings through structured observation, this research identified that people, process, and technology are three core elements of information coordination, and the implementation of technology relies on people and process. Furthermore, the observation results show that the gamificative environment is highly dependent on support from a quality 3D information model. Also, the research found that Common Data Environment is important for access and exchange of data for increasing design collaboration. Based on the findings of how information coordination is impacted, this research amended the conceptual framework to the second stage.

This chapter discusses whether and how this conceptual framework can work on a larger scale by collecting and analysing opinions from different AEC professionals. The results show that the framework is acceptable for implementation in building design companies but there are some limitations due to concerns surrounding difficulty and cost. Furthermore, a lack of sophisticated technology is another concern regarding the mobilization of company resources and activities. Therefore, the research further amended the conceptual framework to the final stage.

5.5.2 Impact of Conceptual Framework on Business Operation

As discussed in the literature review, LOD 350 plays a role in connecting the design and construction stages. The enhancement of LOD 300 to LOD 350 enables sufficient spatial coordination for optimization of building components to detect potential issues before entering the construction stage. As the gamificative environment is designed for improving the interaction between people and virtual environment for detecting undiscovered problems, the 3D information model based on LOD 350 specification will provide a realistic situation for supporting the decision-making process in such an immersive environment. Therefore, LOD 350 has a significant impact on information coordination in the gamification process in building design development.

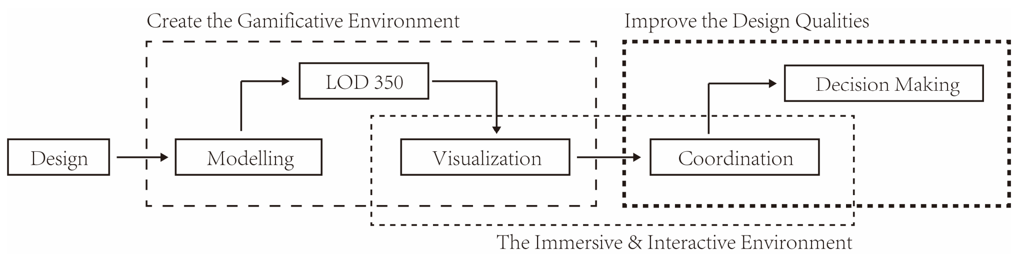


Figure 5.5 a: Impact of LOD 350 on Decision Makings

This research has identified that the impact of information coordination on building design quality needs to be integrated with business operation for sufficiently allocating the relevant resources and activities. The role of LOD 350 is considered as a major activity in the modelling process to realistically visualize building design for the decision-making process. (Figure 5.5.a) highlights three parts of the entire process: creation of the gamificative environment, utilization of the immersive environment, and the improvement of design quality. These three parts progress consecutively. As verified through the conceptual framework, to improve building design quality, an immersive and dynamic environment will contribute greatly. To create such an environment requires sufficient modelling technique and specifications. Hence, the importance of LOD 350 has being significantly shown during the design project development, which aligns with the findings of the literature review and case studies.

For the key perspective during the development of the conceptual framework based on the findings, there are two major factors of particular significance: data accessibilities and data interactivities. According to the findings of the observation from case studies, the information can be developed in a consistent way once the data are accessed. The core of the gamificative environment for design development is to establish the interaction between design data and project team; therefore, data interactivity is another important perspective which is embedded in the conceptual framework. Moreover, the findings from both literature review and case studies have shown that the information coordination of the building design can be improved if the interactivities can be consistently accessed, and the interactivities depend on the combination of multiple technologies. Hence, the conclusion of the findings highlights the significance of Common Data Environment (CDE).

This research has selected three different technical approaches to create gamificative environments for observing how information coordination is impacted. With the findings through the experiment, the role of CDE is highlighted since this is the key aspect associated with data accessibility and data exchangeability during the information coordination process, which impacts the collaboration capabilities of design development. The immersive and interactive environment through visualization in a gamificative way enables people to have better understanding of project design, and hence clear feedback on the requirements and demands can be made for the decision-making process. Improved collaboration and decision making will enable companies to complete the project in an efficient way; thus, the performance of business operation can be enhanced.

The design process is one of the three core sections, according to the analysis results from the qualitative data, because the collected data shows that the quality of information coordination depends on people and process during building design development. The common data environment (CDE) has been confirmed as a suitable information management carrier for the involvement of project participants to make decisions through the information coordination process. The results from the qualitative analysis have shown that communication and problem detection are closely linked with information coordination. Furthermore, from the information coordination, decisions are made based on the collaboration process for taking action regarding any modification requests. Hence, the quality of building design can be improved.

With the intervention of CDE, all project data can be efficiently stored, shared, and developed for creating consistent information to improve the quality of building design. The quality of building design is focused on three perspectives, according to the findings from literature review, which are: to meet with the relevant code and regulations, to meet with client requirements, and to meet with design reasonability. The consistent access to information by project participants can ensure all the design data can be utilized in an appropriate way for establishing assessment and evaluation via the proposed gamificative environment. According to the findings, without CDE, the information model cannot be effectively applied in project development.

The key argument of this research regarding how information coordination can impact business operation is to improve production capabilities. Production capabilities of building design rely on the combination of multiple capabilities, and one of them is the decision-making capability. The capability to make decisions contributes to the quality of building design, allowing design management to impact information coordination. The coordination of design information relies on collaboration and communication capabilities, which can further impact the business operation of project development. Evidence has shown that adoption of the gamificative environment can improve communication and collaboration. Despite the concern of investing extra resources and activities in the short to medium term, company performance can be impacted in long term development, according to the findings of this research.

5.5.3 Final Validate Amended Conceptual Framework

Through the analysis of primary data collected from the focus group discussion and survey, this research has confirmed that the direction of the second stage conceptual framework is correct, albeit with some limitations. Therefore, this section is amending the second stage of the conceptual framework through further development, according to the findings.

The general scheme of the conceptual framework (Figure 5.5.b) is the same as the second stage findings, which is associated with three elements. The project team follows the SMPs to use the Gamificative Technologies during the BIM implementation, and the Gamificative Technologies create the Gamificative Environment within the Common Data Environment for ensuring data accessibility. Building design business operation needs to efficiently allocate resources during information coordination by adopting the proposed conceptual framework because IT mobilization and personnel training will generate extra cost in the short term. The findings agree that the collaboration capabilities will be impacted in the long-term operation. Therefore, this research shows the feasibility of the proposed conceptual framework being adopted during building design practice.

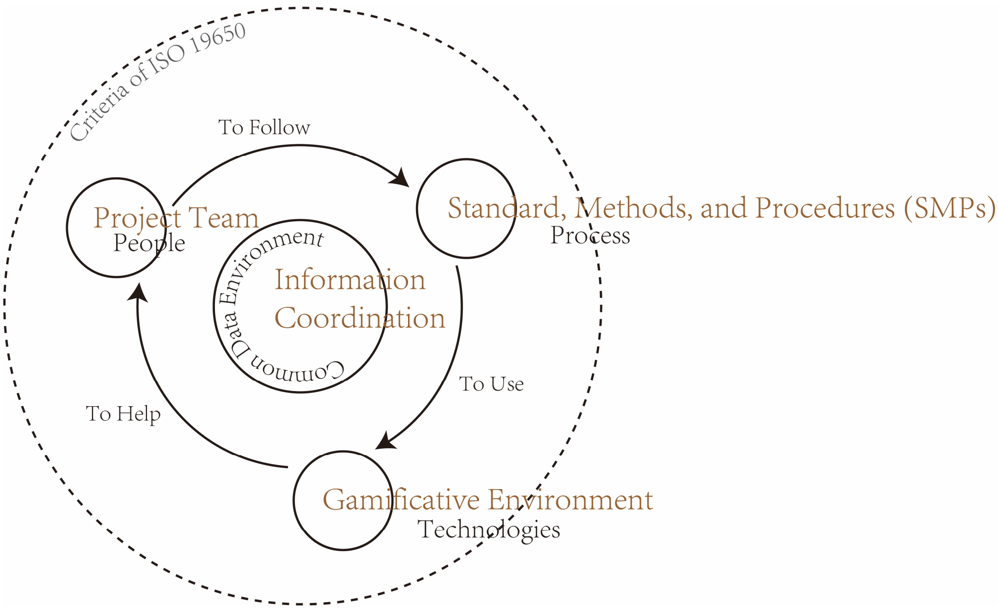


Figure 5.5 b: The Scheme of the Final Conceptual Framework

The Common Data Environment (CDE) is still the most important part in the amended conceptual framework because this the foundation for building design collaboration. Based on the CDE, the established immersive and interactive environment can increase the information coordination of the project development because the data accessibility and exchangeability rely on the CDE regulated by ISO 19650. Decision making is being impacted by comprehensive visualization in an immersive and interactive way. With improved understanding of the project, decisions can be promptly made.

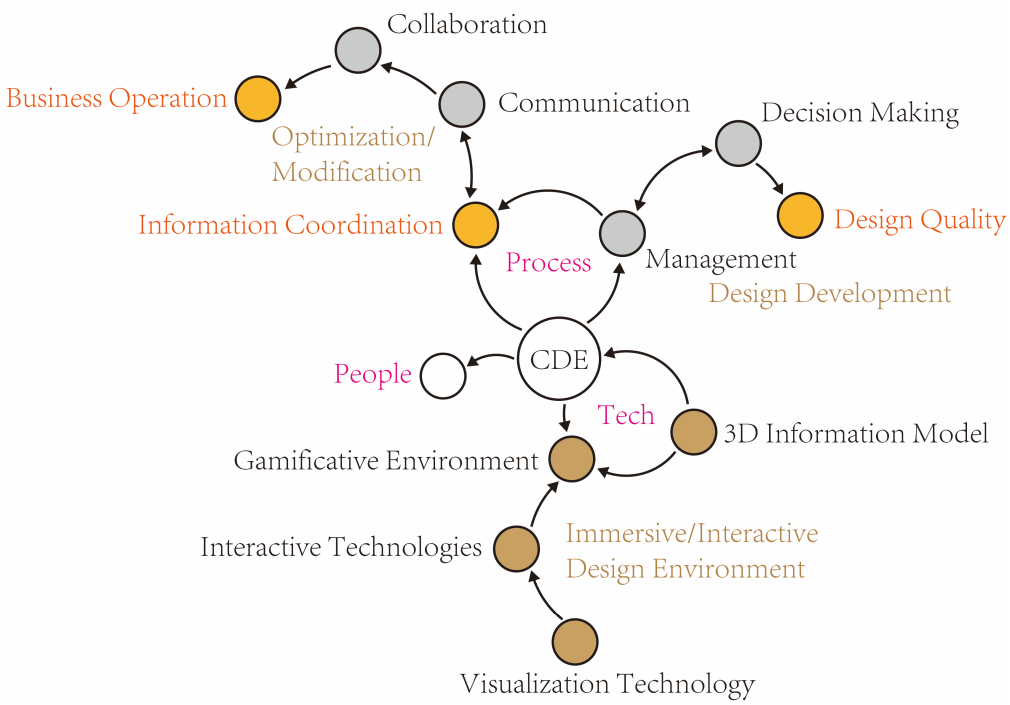


Figure 5.5 c: Relations of the Findings from Focus Group

The final conceptual framework, (Figure 5.5.c) shows the impacts and interrelations of the factors and features from the proposition. CDE is in the central position for ensuring the accessibilities of the project data. The 3D information model determines the quality of the gamificative environment by using interactive and visualization technologies. With the gamificative environment in CDE, the design team can better utilize project information to optimize and modify from the aspects of improved communication. Therefore, the management of building design can increase the efficiencies of decision making and enhance the schedule of the delivery process.

The integration of people, process, and technologies by adopting appropriate SMPs and technologies can increase the coordination of building design information through the gamificative environment, which could subsequently improve design quality and enhance the delivery schedule. The final conceptual framework being proposed by this research integrates all the relevant technologies into Gamificative Technologies, and all the relevant procedures into Process (Figure 5.5.d). Three features of gamificative technologies are associated, which are, visualization, immersiveness, and interactiveness. These features are supported by different systems for contributing to the collaboration process between design team and stakeholders. Also, the project team follows the relevant criteria of information management and building design to properly use the gamificative technologies.

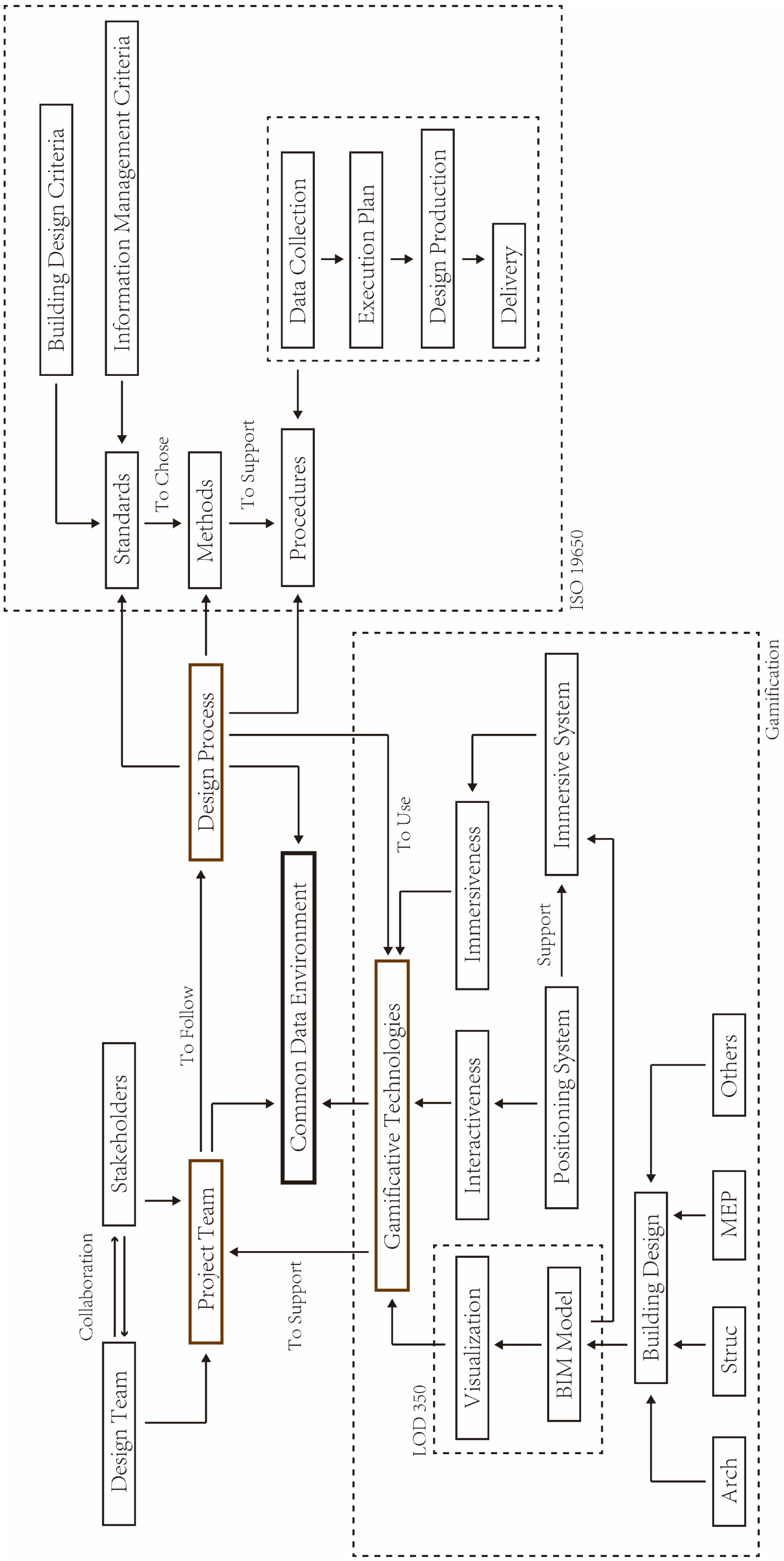


Figure 5.5 d: The Final Validated Amended Conceptual Framework

In Chapter 2, Section 2.6 (**pp. 179**), this research has proposed a proposition (1st version of conceptual framework) to establish the interrelation among LOD 350, ISO 19650, and Gamification based on the findings from literature review. In Chapter 4, Section 4.4 **(pp. 323**), this research has amended the proposition to propose a conceptual framework (2nd version of conceptual framework) based on the findings from action research via three intervention studies. In 2nd version of conceptual framework, this research precisely places the position of LOD 350, ISO 19650, and Gamification along with people, process and technology. Then the research validated the findings from action research through focus group discussion and survey to further measure the feasibilities and the strength of gamificative environment. The results from the validation are developed into final conceptual framework (Figure 5.5.d). In the final one, a much-detailed interrelation between each element is positioned for providing references in building design information coordination to enhance the business operation performance.

5.5.4 The Advantages of the Proposed Conceptual Framework

Building design is a complex process, which requires sufficient information coordination to ensure quality and efficiency. The research has identified four factors that impact on information coordination in the building design process, which are, data visibility, data accessibility, data sufficiency, and data accuracy. Poor development of these factors increases the possibility of project failure; therefore, a solution is required to ensure that these factors are kept to a minimum. For those concerns, consistent focus needs to be applied in three areas: information development, information collaboration, and information management. The development of information requires sufficient collaboration, and the collaboration of information requires efficient management. This research has proposed a good solution to coordinate building design information through development, collaboration, and management perspective. In comparison with solutions from previous research, the proposed solution has significant advantages.

According to the findings, poor information coordination is caused by poor understanding, and poor understanding is caused by poor visualization. Poor visualization is due to poor development, collaboration, and management of project information. Six aspects are identified that impact on project understanding, which are, data interactiveness, data immersiveness, data accuracy, data sufficiency, data access, and data exchange. The proposed solution effectively addresses these concerns to fill the gap by using a gamificative environment in building design development. The advantage of the proposed solution is that it provides a vision to implement BIM in a comprehensive way for enhancing people's understanding of building project development. The solution, specifically created for building design project development. focuses on interactive and immersive ways to establish a comprehensive visualization environment for people to make decisions

The findings from precedent studies have been limited to improving a single aspect of building design, such as interaction, integration, or visualization. These solutions do not fully satisfy demand in building design scenarios; moreover, they are not easy to utilize, and require a lot of training and practice. The industry needs a solution which does not require too much technical involvement, and which people are likely to accept and to utilize in building design development. To fill the gaps and address the limitations from precedent studies, this research focuses on the human aspect to identify what people like, with processes and technologies that are easy to follow and to use. Therefore, the research proposes use of a gamificative environment, which addresses the above concerns.

The gamificative environment proposed by this research is practical, easy to use and understand, and little technical training is required. Compared with previous studies on gamification, instead of merely focusing on concepts, this research provides a solution to really utilize gamification in building design. Thus far, little research has discussed the role of gamification in building design. This research clarifies how the features and characteristics of gamification can impact on information coordination in building design, and fills the gaps in previous studies.

In conclusion, this chapter has finalized the conceptual framework based on the validation results. The findings from the focus group discussion and survey match the findings from the literature/systematic review and the action research. Therefore, the final conceptual framework supports the feasibilities of the proposition to increase information coordination in building design business operation. Compared with solutions from precedent studies, the proposed gamificative environment is less complicated to use and increases people's understanding of building design. The proposed solution is specifically created for building design scenarios and covers most aspects of information coordination in building design development. Both theoretical and practical contributions are made to fill the gaps in gamification in building design management, which can provide a reference for academic research and industry practice.

Chapter 6 Research Conclusion

6.1 Research Summary

Poor information coordination has a negative impact on the operation of building design business. This research aims to discover how to enhance the building design business operation through the improvement of information coordination during the building project development. This applied research explores a particular solution by seeking practical and technical strategies in AEC industries for addressing the identified issue in the management of building design.

Building design consists of graphical information and non-graphical information. Graphical information is presented in the form of diagrams while non-graphical information is presented in the form of sheets. The coordination of graphical information and non-graphical information in building project design is often chaotic. The reason causes the chaos is lacking suitable Standard, Methods, and Procedures (SMPs). Therefore, this research is being conducted aiming to fill this gap.

Having investigated the problems, issues, and solutions in current building design, a wide range of theoretical and technical solutions have been explored in the AEC-related field with the aim of solving the issues identified. According to the findings, the research has identified that problems of information coordination are due to lack of accessibility and interactivity regarding the project data. Hence, theories and state-of-the-art technologies have been integrated by this research to address the problem and a new strategy in BIM-driven building design project development has been proposed.

Starting with accessibility and interactivity, this research has conducted three stages of study: literature review, action research, and focus group discussion & survey, for identifying how the situation can be improved. With the findings from each stage, the research has developed a conceptual framework. Three stages of conceptual framework are progressively developed by adding new elements through the findings. This conceptual framework guides building design companies to efficiently implement a 3D information model through the BIM-driven project.

The core aspect addressed by this research is the increase of information coordination; therefore, solutions have been explored for solving problems regarding how project data can be efficiently allocated. With the findings, an interactive and immersive environment has been proposed, for the coordination of building design information by combining different theories and technologies. This is known as a Gamificative Environment. Through this environment, project data can be efficiently accessed and interacted with for increased information coordination.

The gamificative environment proposed by this research is integrating both graphical information and non-graphical information through the combination of people, process, and technologies. The proposed solution to establish a gamificative environment in building design include three foundations, which are, Level of Development (LOD), ISO 19650 (Information Management), and Gamification. LOD is adopted for ensuring all the graphical and non-graphical information can be produced in an accurate and sufficient way; ISO19650 is adopted for ensuring the production of graphical and non-graphical information can meet with SMPs; while Gamification is adopted for ensuring the understandings of design projects.

Through testing gamificative technologies through the experiment in intervention studies and findings from focus group discussion, this research has confirmed the feasibility of the proposed solution, which can impact information coordination and subsequently impact the quality of building design and business operation. Furthermore, the research has used surveys to measure the strength of each feature and their capabilities within the gamificative environment.

This research has investigated how the coordination of design information needs to be conducted during the development of building design to support its management. The relationship between different building components, the role of detailed specifications, and the impact of visualization strategies has been carefully studied to explore how information coordination can be increased to enhance building design business operation performance (Figure 6.1.a).

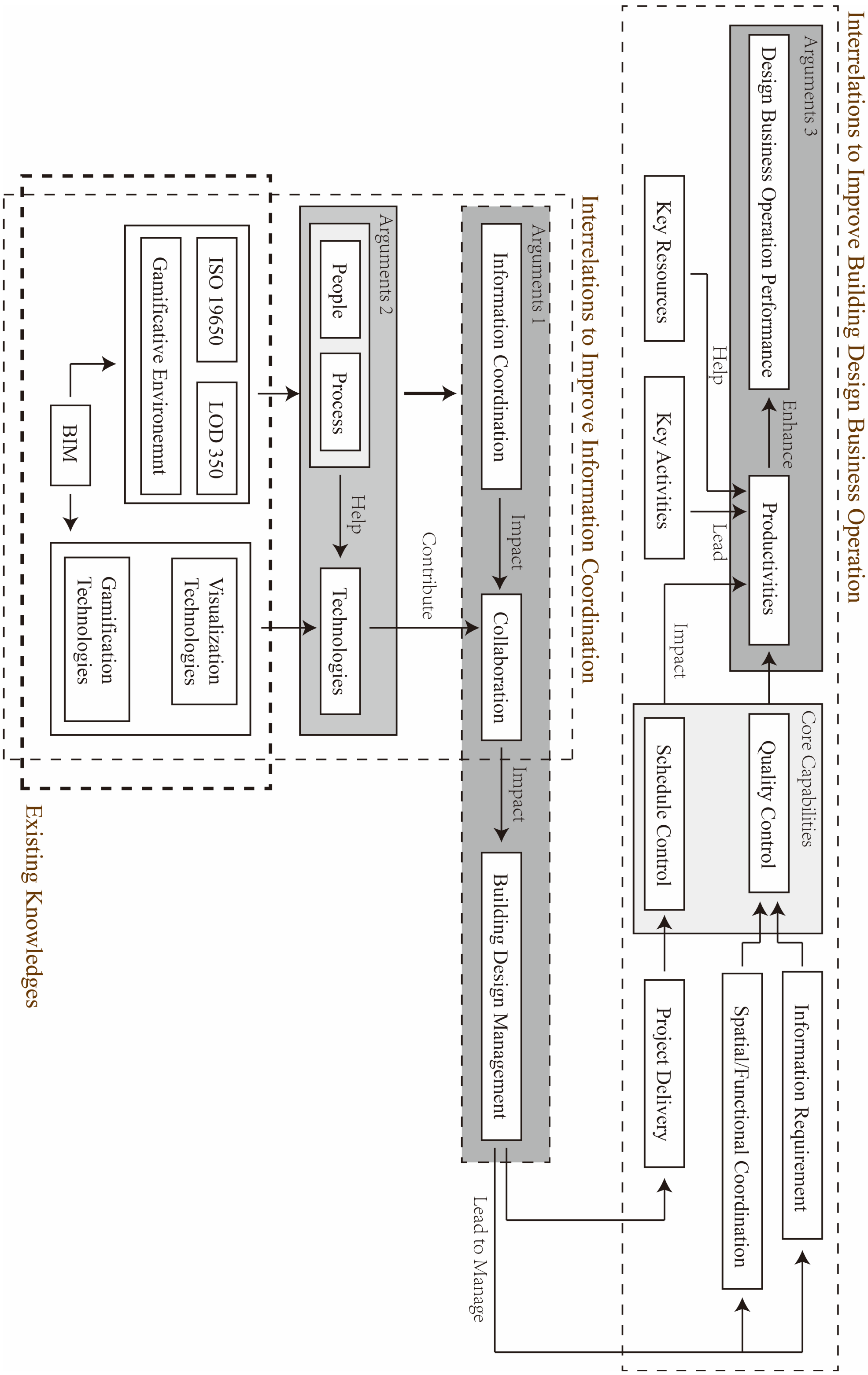


Figure 6.1 a: Research Summary

The proposed conceptual framework consists of three aspects: LOD 350, ISO 19650, and Gamificative Environment. The major innovation of this research is establishing the link between Information Model and Building Design Development, which has provided a reference for design business during the implementation of BIM.

6.2 Research Assessment

The assessment of this research is to investigate each of the research objectives, followed by research aims, which are:

- Objective 1: To investigate factors in building design information coordination.
- Objective 2: To understand the impact of LOD 350, ISO 19650, and Gamification on each factor of building design information coordination.
- Objective 3: To validate whether and how information coordination can improve building business operation.

The first research objective is explored through the literature review and semi-structured interview. The second research objective is explored through action research and literature review. The third research objective is explored through case studies and focus group discussions (Table 6.2.a).

Table 6.2 a: Research Methods Summary

	Location	Methods	Data Type
Ob1	Chapter 1	Semi-structured Interview	Primary Qualitative
Ob2	Chapter 2	Systematic and Literature Reviews	Secondary Quantitative
Ob3	Chapter 4	Action Research	Primary Qualitative
	Chapter 5	Focus Group Discussion	Primary Qualitative & Quantitative
	Chapter 5	Survey	Primary Quantitative

Three research objectives are discussed through four chapters. Different data types are listed in the table to show how the research develops the study. The specification of data collection and analysis methods are discussed in Chapter 3.

The collected data are carefully processed, analysed, and archived to explore each of the objectives for validating the final proposed conceptual framework.

6.3 Research Findings

The findings show that the problems in building design business operation are concentrated in the coordination of design information to increase production capabilities. The research uses different methods to address each objective, the findings from each research objective are as follows:

- For the first research objective, five factors of information coordination in building design are identified: data accessibilities, data exchangeabilities, data visibilities, data accuracy, and data sufficiency (See Figure 6.3.a). This research has identified that collaboration is an important aspect in coordination of building design information, which will impact on design team productivity.

- For the second research objective, LOD 350 impacts on data accuracy and data sufficiency, ISO 19650 impacts on data accessibilities and data exchangeabilities, and Gamification impacts on data visibilities (see Figure 6.3.b). In particular, this research has verified that the features of LOD 350 can help digital building components reach a realistic quality in relevant geometry, the process regulated in ISO 19650 can help the design team to better develop the project data, and the characteristics of gamificative technologies can improve people's understanding toward building projects.

- For the third research objective, increased information coordination within a gamificative environment can improve people's understandings to increase the productivity, hence impacting on business operations. The intervention of the gamificative environment in CDE can result in more efficient communication compared with traditional solutions. Thus, people, process, and technologies can be better integrated for enhancing the information management of building design, which can lead to improved design quality and delivery schedule, subsequently impacting productivity in building design production and enhancing business operation performance.

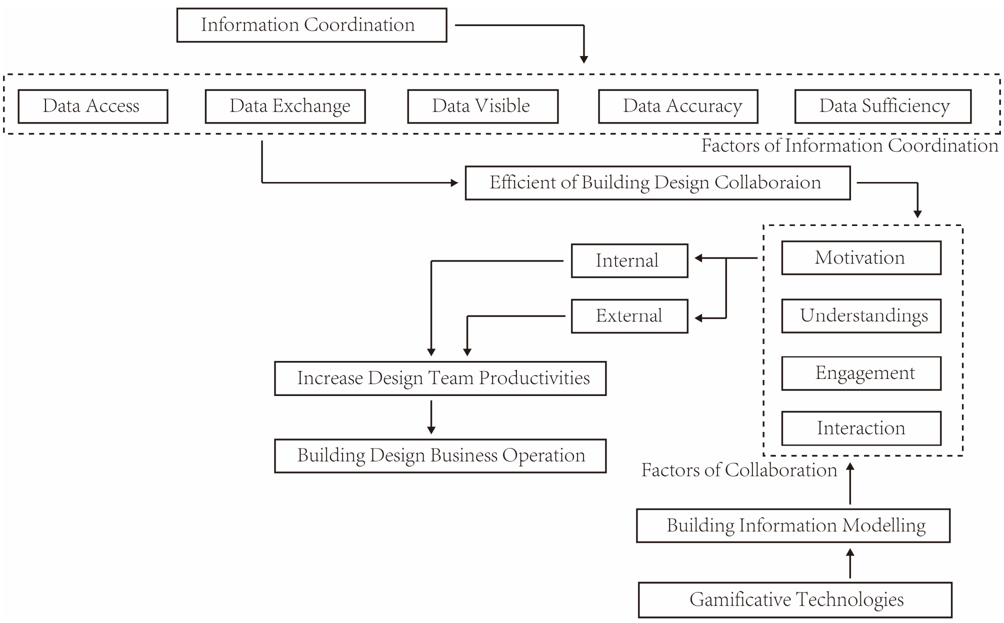


Figure 6.3 a: Interrelation between Information Coordination and Gamificative Technologies

Four factors have been identified from the gamificative environment which established the interrelation between the gamificative environment and building design business operation, which are: motivation, understanding, engagement, and interaction (See Figure 6.3.a). Findings show that business operation is directly linked with production capability, which includes quality control and schedule control (see Figure 6.3.b), and with the integration of LOD 350, ISO 19650, and Gamification, information coordination in building design can be increased to enhance building design business operation performance.

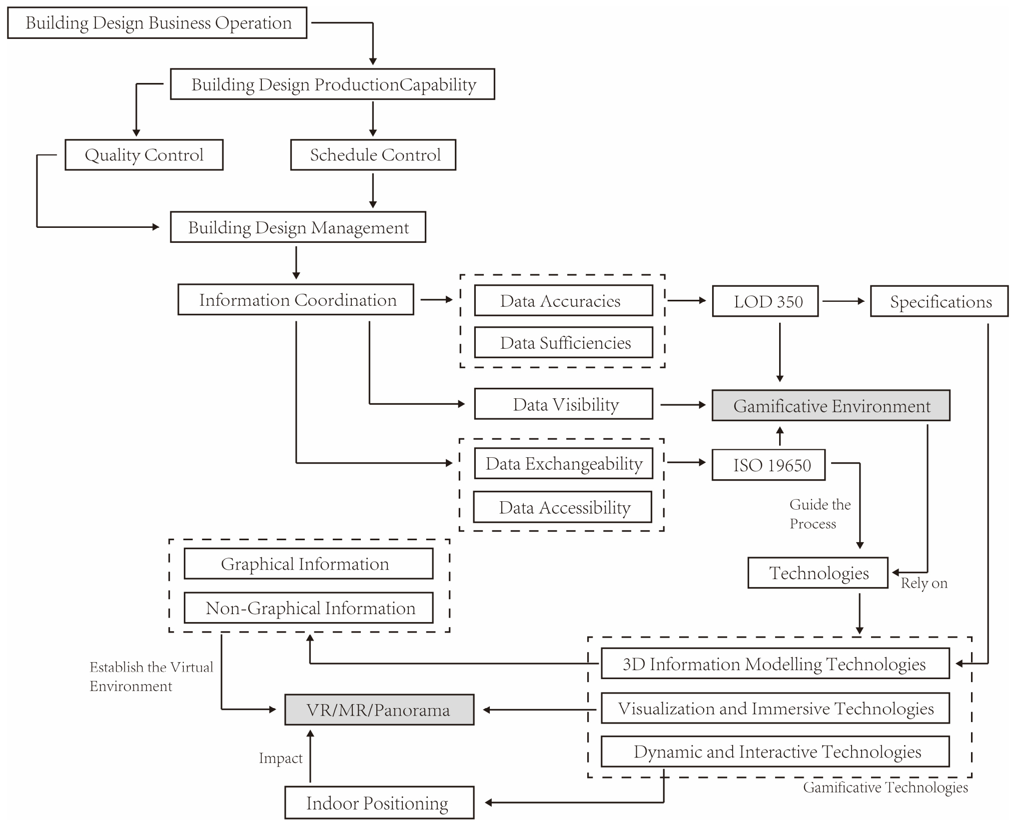


Figure 6.3 b: Interrelation between Business Operation and Gamificative Environment

Therefore, the impact of the gamificative environment on building design business operation has been validated. The research identified that the gamificative environment in building design can help to:

- ✧ Improve interaction between people and building design to increase collaboration.
- ✧ Improve visualization in a virtual environment to increase project understanding.
- ✧ Improve the engagement of project participants to increase design team productivity.

There are three stages of impact, as follows: gamificative environment impact on project understanding, project understanding impact on design team productivity, and productivity impact on building design business operation.

Hence, this research has proposed a new direction in how BIM can be implemented in building design business operation.

6.4 Novelty of the Research

This research has provided a solution to increase information coordination in building design by integrating people, process, and technology to improve people's understanding of a project. The core value of this research is that it provides a reference for building design companies to increase design team productivity to enhance business operation performance.

This research has explored the problems and issues in building design management and has investigated the key aspects in coordination of design information. Specifications for developing a 3D information model in BIM-driven projects have been explored, and the role of LOD 350 has been clarified for spatial integration of information coordination. Based on the findings of the integration process of virtual building components in design development, this research has investigated how to increase interactivity between people and virtual environment for improving the visualization and coordination process. The proposed solution to create a gamificative environment followed by the adoption of gamification in business operation enables efficient integration of people, process, and technology in building design projects.

The novelty of this research is mainly focused on data visualization aspects, in particular the development of interactivity and immersiveness. Compared with previous research, this research has provided a vision in building project data presentation to support decision making. The value of adopting the proposed gamificative environment in building design is that the interactive and immersive virtual environment can enable people to establish sufficient understanding toward project development in a Common Data Environment (CDE), which is a commonly accessible environment for data exchange. Moreover, the virtual environment is created based on Building Information Model (BIM), which covers every critical building component for simulation, evaluation, and assessment. Therefore, the proposed solution can allow project participants to forecast those potential problems at the early stages through a genuine digital environment. Hence, the coordination of building design information can be efficiently increased due to the elimination of misunderstandings.

Another significant novelty of this research is the integration of interaction, immersiveness, and information models, which not only provides a comprehensive and holistic environment for design review, but also enables people to realistically interact with the design. The proposed solution for visualization is not merely a 3D rendering for reviewing, but more of a digital world for exploration. The outcome of this research is a conceptual framework, which concentrates the findings from building design management, AEC technologies, and building design business operation. This conceptual framework has filled the gap in how to integrate people, process, and technology in building design projects, which has provided a vision and a reference for information coordination in building design process. The uniqueness of this conceptual framework is in its holistic view, rather than focusing on a single aspect.

The key contribution made by this research is in providing a vision through the conceptual framework to effectively use the 3D information model developed in BIM-driven projects for establishing interaction between project team and virtual design environment. Thus, through efficient communication, collaboration, and coordination process, the quality of building design can be increased. This conceptual framework can be used by all project participants in an AEC-related project to improve the performance of project development. A systematic approach of information model development and utilization has been established by the conceptual framework, which also provides a direction for further theoretical development of building information modelling.

6.5 Future Work

This research has created a conceptual framework based on aspects identified in the coordination of design information. Those key aspects in information coordination need to be focused on integration, interaction and management. Therefore, based on the findings, this research has adopted integration of LOD 350, ISO 19650 and Gamification to efficiently coordinate building design information. Although this conceptual framework can effectively provide reference for developing a 3D information model in the BIM-driven project, feedback from the interactivity of people and virtual environment cannot be simultaneously modified through the common data environment. Therefore, additional work needs to be conducted, which will waste time during the coordination process.

This research is restricted by current technical solutions in the Common Data Environment (CDE); the current existing CDE cannot provide a real-time modification function to link directly with the database of modelling tools. The relevant modification based on the design assessment cannot be made during the evaluation process, and this issue needs to be resolved in future research. This is not a technical problem, as relevant software can be developed based on demand. However, it is not clear what type of CDE can be used, and how the system architecture should be built for efficiently conducting modification from the evaluation. Hence, future research will be focused on understanding the requirements of the information container regulated by ISO 19650, which is the requirement of the Common Data Environment in BIM-driven projects.

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Appendix

A.1 Research Impacts

A.1.1 Publications

Yang, T., Kapogiannis, G., Kang. B., Wilson, R. (2020). Impact of Level of Development (LOD) 350 of BIM models in building construction documents design. *Journal of Information Technologies in Civil Engineering and Architecture, 12*(4): 1-17. https://doi.org/10.16670/j.cnki.cn11-5823/tu.2020.04.01

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A.1.2 Awards

- ✧ 2021.1, FIG, Article of the Month (February)， Monthly Article
- ✧ 2020.12, First Prize, The 2nd GongChuang-Cup Intelligent Construction Technology Innovation Competition, University Group 第二届共创杯智能建造技术创新大赛高校组一等奖
- ✧ 2020.12, 2020 Gold Prize, China Smart Construction Application

Competition Award, University Group. 2020 智建杯智能建造应用大赛高校组金奖

- ✧ 2020.11 Best Rookie Award, AEC Hackathon 2020@Shanghai 建筑黑客松 2020 上海站，极客新秀奖
- ✧ 2020.9 Best Paper Award, The 7th International BIM Technology Conference – "Intelligence Construction and Architecture Industrialization and Innovation Competition".
- ✧ 2020.5 Tri Campus Postgraduate Award 2020, University of Nottingham
- ✧ 2020.7 Winning Prize, The 2nd Ningbo JianGong-Cup BIM Technologies Application Achievement Competition, University Group 宁波市第二届建工杯 BIM 技术应用成果大赛（团队赛）高校组优胜奖
- ✧ 2019.12 First Prize, The 1st GongChuang-Cup Intelligent Construction Technology Innovation Competition, University Group 首届共创杯智能建造技术创新大赛高校组一等奖

A.1.3 Public Presentations and Speeches

- ✧ 2021.5 Nanning BIM seminar, with Dr. Georgios Kapogiannis, BIM in technical education.
- ✧ 2021.3 Shengzhen BIM conference, online, with Dr Georgios Kapogiannis, Gamificative environment as supporting for decision making process.
- ✧ 2020.12 Beijing BIM technologies forum, online, with Dr. Georgios Kapogiannis, Gamificative Environment in Facility Management.
- ✧ 2020.11 Hangzhou West Lake AEC Robot Forum, with Dr. Georgios Kapogiannis, RoboBIM in AEC industries.
- ✧ 2020.9 Guangzhou International BIM forum, with Dr. Georgios Kapogiannis, BIM, digital construction, and future perspectives.
- ✧ 2020.9 Hangzhou Smart Construction Forum, with Dr. Georgios

Kapogiannis, introducing Digital Construction.

- ✧ 2020.8 Shanghai Construction Group, introducing ISO 19650.
- ✧ 2020.2 BuildingSmart China Digital Technology Conference, ISO 19650, and BIM, Online
- ✧ 20219.12 Beijing BIM technologies communication conference, with Dr. Georgios Kapogiannis, Gamification in Building design.

A.1.4 Teaching

- ✧ 2018-2021 Graduate Teaching Assistance of Dr. Georgios Kapogiannis, ABEE 4049 BIM and Future, University of Nottingham Ningbo China
- ✧ 2018-2021 Graduate Teaching Assistance of Dr. Georgios Kapogiannis, ABEE 3029 Building Information Modelling & Management, University of Nottingham Ningbo China
- ✧ 2018-2021 Graduate Teaching Assistance of Dr. Georgios Kapogiannis, ABEE 4048 Global Smart City with Integrated BIM, University of Nottingham Ningbo China
- ✧ 2018-2021 Guest Lecture, CIVE 4109, University of Nottingham Ningbo China
- ✧ 2020.10.15 Guest Lecture, ABEE 2025, IDA2, University of Nottingham Ningbo China

A.1.5 Qualifications Achieved During the PhD Research

- ✧ 2019.Oct: BRE BIM ISO 19650 Information Manager
- ✧ 2020. May: BRE BIM ISO 19650 Certified Trainer
- ✧ 2020.Oct: Autodesk Revit Authorized Instructor

A.2 Data Collection Question and Sheets

A.2.1 Semi-structured Interview Questions

Part 1: Architecture Discipline 尊敬的建筑设计师，您好， Dear Architecture Designer,
1.在建筑施工图的设计过程中，您认为最重要的是向各方（其它专业，包括施工、预算）表达什么信息？ During the architecture construction drawings, what are the most important things that you think need to deliver to different participant (other professionals, including construction and budget)?
2.建筑施工图的复杂节点与详图设计中，您认为在图面表达上有哪些数据和信息容易遗漏？ During the complex detail drawings, which data and information that you think are most likely to missing?
3.在建设工程施工图的设计中，根据您的经验，您认为结构、水电、设备等专业需要在哪些时间点向建筑专业反馈哪些数据来完善最终建筑施工图设计？ During the building project construction drawing design, according to your experience, when and what do you think other disciplines (structure, water, electricity and HVAC) need to give you feedback for completing the final architecture construction drawings design?
4.作为建设工程施工图设计的主要专业，您认为在多专业协同合作中应该如何主导有效的沟通？ As the main discipline in building project construction drawing design, do you think what are the factors to conduct effective communication among multi-discipline coordination?
5.您认为建筑设计工具需要具备哪些功能？ What functions do you think architecture design tools need to have?
6.在建筑施工图的设计中，为了避免误解和加快效率，您认为在方案设

计阶段应该完善哪些数据? During architecture construction drawing design, to avoid misunderstandings and improve efficiency, what data and information that you think need to be improved during concept design stage?
7.在收到其它专业反馈数据并且进行多专业协同合作的阶段，您认为有哪些因素会影响多专业沟通交流并影响您对建筑施工图设计的最终完善? After receiving feedbacks from other discipline and doing multi-discipline coordination, what factors do you think will affect communication, and what are the factors that will impact to the progress of architecture construction drawings?
8.作为建设工程施工图设计的领头专业，您认为在第一阶段的设计上应该如何避免之后各专业之间的设计碰撞? As lead-discipline in building project construction drawings design, what do you think that need to be aware in the beginning in order to avoid clash caused by insufficient design coordination?
非常感谢您的时间，祝您工作顺利，生活愉快! Thank you very much for your time and wish everything is going well on you!

Part 2: Structure Discipline 尊敬的结构工程师，您好， Dear Structure Engineer,
1.在建设工程施工图设计阶段的跨专业协同合作中，您认为最需要注意的问题是什么? What is the issue that need to be mostly get attention during cross-discipline coordination in building construction drawing design?
2.在与建筑专业配合进行施工图设计的时候，您认为哪些因素会影响设计进度? What are the factors that will delay the progress while cooperation with architecture discipline in construction drawings design?

3.作为结构工程师，为更好地进行结构设计，您认为建筑专业在建筑施工图上应该提供哪些数据？ As Structure Engineer, what data do you think that Architecture Designers need to provide for structural construction drawing design?
4.在结构施工图设计时，您认为应该给予建筑设计师哪些反馈数据？ What data do you think that you need to give feedback to architecture designer while structure construction drawings design?
5.作为结构工程师，您认为有哪些地方会产生与建筑设计师不统一的意见。 As structure engineer, what are the factors do you think you will make disagreement with architecture designer?
6.您认为结构设计工具应该提供哪些功能？ Which functions do you think structure design tools need to provide?
7.您认为建筑施工图设计深度不足时，会对结构施工图设计带来哪些影响？ If the architecture construction drawings do not reach enough depth, what do you think will impact to structure construction drawings design?
8.在建筑施工图的详图设计上，为了避免产生误解，您认为建筑设计师应该如何表达图面？ To avoid misunderstandings, what do you think architecture designers need to present their detail drawings?
非常感谢您的时间，祝您工作顺利，生活愉快！ Thank you very much for your time and wish everything is going well on you!

Part 3: Construction Supervision Discipline 尊敬的监理工程师，您好 Dear Construction Supervisor,
1.从施工参与方的角度来看，建设工程的施工图设计应该如何表达图面（平面、立面、剖面）？

From construction side, what need to be presented and illustrated in construction drawings (plans, elevations, sections)?
2.施工图节点详图的设计和说明上，为了确保施工人员不会产生误解，您认为设计人员应该如何去明确表达详细的图面和完整的做法？ To avoid misunderstandings by construction personnel in detail drawings, what do you think designers need to present diagrams and explanations?
3.在施工的过程中，您认为施工图设计的哪些因素会导致施工单位反复多次联系设计单位进行确认和提出修改？ During the construction, which factors do you think will cause construction party repetitively contact design party to request clarification and modification?
4.建设工程的施工图通常分为五个专业，您认为每个专业的施工图的设计深度应该达到什么程度，才能使施工方顺利进行作业？ Building construction project usually includes five disciplines, what depth of construction drawings do you think that each discipline needs to reach?
5.作为施工的参与方，您认为在施工过程中会产生哪些设计方和施工方之间的不协调？ As construction participant, what are the discordant you think that are existing between design party and construction party during construction progress?
6.您认为建设工程的施工图设计文件应该通过什么样的介质来传达，这些介质（例如，蓝图、CAD 文件、三维模型）之间的优缺点分别是什么？ What media do you think that construction documents should be carried, what are the advantages and disadvantages of these media (blueprints, CAD files, 3D-models)?
7.您认为现阶段各专业的施工图设计通常存在哪些问题和不足之处？ What are the problems and insufficiencies do you think that those construction drawings usually have?
8.您认为设计单位应该如何与施工参与方进行协同合作来高效完成项目工程的建设？ How do you think design party need to coordinate with construction party for

efficiently complete building project？
非常感谢您的时间，祝您工作顺利，生活愉快！ Thank you very much for your time and wish everything is going well on you!

A.2.2 – Focus group Discussion Workshop

The following slides are presented in the focus group discussion before data collection.

本次研讨会的目的 Purpose of the Focused Group

- 介绍建筑业所存在的技术问题以及最新的技术发展。Introduced the current technical issues in AEC industries and up-to-data Development of technology innovation.
- 介绍在建筑设计阶段的BIM研究成果。Introduce the research outcome of BIM in the building design stage.
- 讨论课题研究成果的可行性。Discuss the feasibilities of the research outcomes.

建筑业的最新发展 AEC Development

- BIM技术的不断发展为建筑设计提供了一个全的新思路。The development of BIM Technologies has provided a new solution for building design.
- BIM的三大要素为：图像信息，非图像信息，数据存档。Three important aspects of BIM is Graphical Information, Non-Graphical Information, and Documentation.
- 通过BIM的图像信息，建筑设计可以将设计与可视化进行深度融合，提高设计各参与方与设计的成果进行互动。Through the graphical Information of BIM model, Building design can integrate design with visualization, and can improve the interaction between project participants and building design.
- 通过虚拟现实，混合现实等技术，BIM模型可以通过沉浸式的方式进行呈现，提高设计各参与方的决策能力。Through VR and MR, BIM model can be visualized through immersive way for improving the capabilities of decision makings of project participants.
- 基于ISO 19650信息化管理标准，建筑设计在管理上可以对信息协调进行多专业整合与优化，提高设计交付的质量。Based on ISO 19650, building design can be managed through information coordination and optimization for improving the quality of design delivery.

建筑设计中的最大问题

- 根据研究的结果表明，在建筑设计中，最大的问题在于项目的各参与方协调的不充分，这将会导致后续一系列的问题：According to the research, the biggest issue in building design is insufficient coordination among project participants, which will cause a series of problems in the later process.

➢空间占位上的冲突 Conflicts in the spatial coordination
➢使用功能上的冲突 Conflicts in functional coordination

✓研究进一步发现，产生这个问题的最主要原因是，项目各参与方缺乏足够的与三维信息模型之间的互动。The further research has identified that the major problem to cause this is, lack of enough interaction between people and 3D information model.

游戏化的介绍 Introduction to Gamfication

游戏化作为一种商业的模式，在非游戏的场景中采用游戏设计的方法，旨在提高人对于某样事物的兴趣，来增加人与事件的交互性，以及提高人对于事物的整体体验。游戏化是一个抽象的概念，重点的内容集中在以下几个方面：Gamification as being a business mode, it uses methods of gamificative idea in those non-gamificative environment, which aims to raise people's interests for increasing the interactivities between people and objects. Also, the holistic experience can be improved through this way. The gamification is an abstract concept, which highlight the following aspects:

➢沉浸式的体验 Immersive experience.
➢明确的反馈 Clear feedbacks
➢可分享的技巧 Sharable technologies

✓本研究指出，通过游戏化的场景能够有效解决建筑设计上的一些问题。This research has identified that through the gamificative environment, it can effectively solve some issues in building design.

游戏化环境的介绍 Introduction to Gamificative Environment

- 本研究提出四种不同的游戏化环境的运行方案，分别为：This research has come up with four different gamificative environment, which are:

➢普通的游戏操作场景 Regular Game interface
➢全景图像的操作场景 Panorama-based interface
➢虚拟现实的操作场景 VR-based interface
➢混合现实的操作场景 MR-based interface

接下来为大家展现这四种游戏化环境在建筑设计中的作用。The following slides are showing how these four gamificative environments is going to work in building design.

普通游戏场景 Regular game interface

优点：Advantages

➢便于输出和操作 Convenient for output and operate
➢容易上手 Easier to be used
➢每个人都可以熟练地探索建筑的每一个角落 Can efficiently explore each corner of the design in virtual environment

通过游戏场景化的输出，建筑设计可以被容易地进行可视化的浏览，以提供及时的反馈。Through the output from gamificative environment, building design can be visualized in an efficient way for providing the feed backs.

全景图像的场景 Panorama Interface

优点：Advantages

- 便于储存和浏览，可以把数据储存在云端，通过二维码和链接在即时通讯软件（例如QQ和微信）进行分享。Cloud-based database allows to conveniently access the data, and the data can be shared via instant message tool (e.g., QQ and Wechat)
- 便于操作。Easy to be used
- 直观性较强。Very direct to be visualized

通过全景图像的输出，设计人员可以便捷地通过云端将设计传送给设计各参与方进行评估。Through the output from the panorama images, project can be delivered to project participants for assessment via cloud.

虚拟现实场景 Virtual Reality Interface

优点：Advantages

- 沉浸式的设计展示环境。Immersive Design presentation Environment
- 互动式的展示场景（实时位置追踪）Interactive presentation environment (real-time position tracking)
- 真实比例的场景 Real scale of the scenario

通过虚拟现实的展示技术，设计团队和项目各参与方可以更加全面地了解建筑设计的空间和功能。Through the virtual reality, project team and design team can have a comprehensive understandings of the building design regarding to the space and functions.

混合现实的场景 Mix-reality Interface

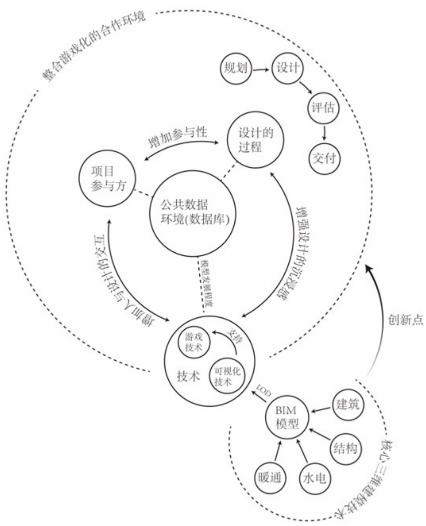
优点：Advantages

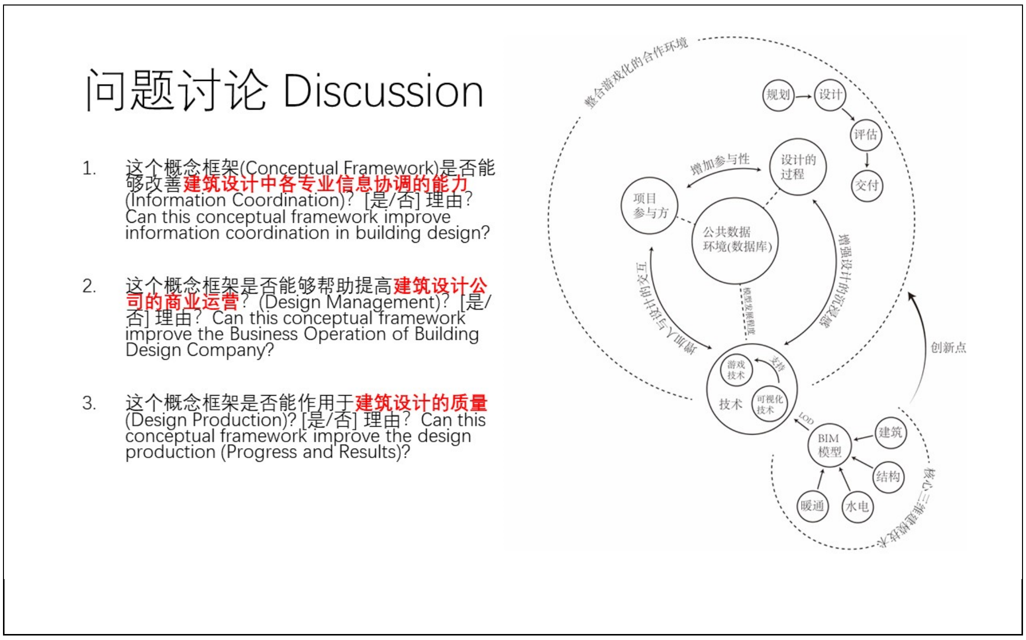
- ➢极大提高人与三维信息模型的互动。Improves the interaction between people and 3D information model.
- ➢提高三维模型与现实环境的融合。Improve the merge between real world and virtual environment.
- ➢全方位对模型进行浏览和操控。Comprehensively review and control of the model.

通过使用混合现实的展示环境，设计所得到的三维信息化模型可以与现实的环境进行深度的融合，为提高与模型的互动做出基础。Through the mix-reality visualization environment, the 3D information model can be merged with reality world in a depth way, for making the foundation of the interaction between people and model.

概念框架的结论
Findings to the conceptual Framework

1. 在建筑设计中，空间的协调和功能的协调对设计中的信息协调有着重要的影响。In building design spatial coordination and functional coordination has high impacts to the design information coordination.
2. 在建筑设计公司的商业运营中，增加项目参与方与设计的互动能够提高信息协调的能力和质量。In the business operation of the building design company, increase the interactivities between stakeholders and design teams can improve the quality of information coordination.
3. 在建筑设计过程中采用游戏化的方式能够作用于设计的过程和结果。The gamificative way during the building design development can impact on the process and results of building design.





A.2.3 - Survey Questions

(0) is not agree 表示不同意, (10) is most agree 表示非常同意

➢ 1. ***Features of Gamificative Environment*** could impact on **Building Design Information Coordination**. 游戏化环境的特征可以作用与**建筑设计的信息协调**。

1.1 **(Data) Immersiveness** of Gamificative Environment could impact on **Information Coordination** during the building design development. **（数据）沉浸体验**可以在建筑设计中影响**信息协调**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

1.2 **(Data) Interactiveness** of Gamificative Environment could impact on **Information Coordination** during the building design development. 在游戏化环境中**（数据）互动性**可以在建筑设计中影响**信息协调**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

1.3（**Data**）**Accessibilities** of Gamificative Environment could impact on **Information Coordination** during the building design development. 在游戏化环境中**（数据）访问性**可以在建筑设计中影响**信息协调**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

1.4（**Data**）**Visualization** of Gamificative Environment could impact on **Information Coordination** during the building design development. 在游戏化环境中**（数据）可视化**可以在建筑设计中影响**信息协调**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

1.5 **(Data) Comprehensiveness** of Gamificative Environment could impact on **Information Coordination** during the building design development. 在游戏化环境中 **（数据）全面性**可以在建筑设计中影响**信息协调**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

➢ 2 ***Information Management*** within a Gamificative Environment could impact on **Building Design Quality**. 在游戏化环境中的信息管理能作用于**建筑设计的质量**。

2.1 **Reliability of Information** within a Gamificative Environment could impact on the **Building Design Quality**.

在游戏化环境中**信息的可靠性**可以在建筑设计中影响**建筑设计质量**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

2.2 **Clarity of Information** within a Gamificative Environment could impact on the **Building Design Quality**.

在游戏化环境中**信息的清晰性**可以在建筑设计中影响**建筑设计质量**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

2.3 **Precision of Information** within a Gamificative Environment could impact on the **Building Design Quality**.

在游戏化环境中**信息的精确性**可以在建筑设计中影响**建筑设计质量**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

2.4 **Proficiency of Information** within a Gamificative Environment could impact on the **Building Design Quality**.

在游戏化环境中**信息的充分性**可以在建筑设计中影响**建筑设计质量**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

2.5 **Consistency of Information** within a Gamificative Environment could impact on the **Building Design Quality**.

在游戏化环境中**信息的一致性**可以在建筑设计中影响**建筑设计质量**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

- 3. ***Improvement of Design Production Capability through Information Modelling and Management*** within a Gamificative Environment could impact on **Building Design Business Operation**. 在游戏化环境中通过信息建模和管理提高设计生产能力可以作用于**建筑设计公司的商业运营**。

3.1 **Technical Skill** in Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理的**技术能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.2 **Human Interaction Capability** in Information Modelling and Management within a Gamificative Environment could Impact on **Building Design Business**

Operation.

在游戏化环境中进行信息建模和管理的**人员互动能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.3 **Forecast Capability** Using Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**预测能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.4 **Executive Bespoken Request** Using Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**对请求的执行能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.5 **Internal Collaboration Capability** Using Information Modelling and

Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**团队内部合作能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是								
	0	1	2	3	4	5	6	7	8	9	10

3.6 **External Collaboration Capability** Using Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**与外部团队合作能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是								
	0	1	2	3	4	5	6	7	8	9	10

3.7 **Clients and Designer Expressing Capability** Using Information Modelling and Management within a Gamificative Environment could Impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**表达能力（甲方与设计团队）**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是								
	0	1	2	3	4	5	6	7	8	9	10

3.8 **Ensuring Common Understanding on Project Specifications between Stakeholders** Using Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中采用信息建模和管理来确保**各方对项目一致的理解能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.9 **Planning Capability** Using Information Modelling and Management within a Gamification Environment impact on **Building Design Business Operation**.

在游戏化环境中进行信息建模和管理所带来的**计划能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

3.10 **Improved Organizational capability** Using Information Modelling and Management within a Gamificative Environment could impact on **Building Design Business Operation**.

在游戏化环境中采用信息建模和管理来**提高筹办能力**可以作用于建筑设计的**商业运营**。

Influence Degree 程度	No 否	Yes 是									
	0	1	2	3	4	5	6	7	8	9	10

A.3 Researcher Information

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